QUALITY CONTROL CONFERENCE PAPERS 1951

FIFTH ANNUAL CONVENTION

AMERICAN SOCIETY
FOR
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MAY 23, 24, 1951

CLEVELAND, OHIO

"QUALITY CONTROL — TODAY'S FOUNDATION FOR TOMORROW'S REPUTATION"

PRICE

$3.00 At The Conference

$3.50 If ordered by mail

Printed in the United States of America
by
ASHBY INCORPORATED
Erie, Pa.

FOREWORD

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QUALITY CONTROL ELIMINATES UNNECESSARY OPERATIONS

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Every year American industry is producing more goods and services per unit of manpower. The steady increase in productivity from year to year makes this nation the greatest producing nation in the world. There will have to be more progress along this road before the problems facing this nation in its defense mobilization efforts are solved.

Increased productivity in manufacturing industries is usually thought to be brought about through better designs, better equipment, or better materials. There are some other ways to increase productivity, particularly with the available equipment and man power. One way is to locate and eliminate the number of manufacturing operations that are unnecessary.

Manufacturing operations that fit into this class may be located by examining such operations performed to "qualify" a part for a subsequent operation or to "correct"some previous operation or process that was not satisfactory. As an example:- Rotors for small motors formerly were rough turned in a turret lathe to "qualify" them for a finish turn operation, in order to maintain diameter and concentricity requirements. This "qualifying" operation which will be discussed later was determined unnecessary by quality control analysis and was eliminated. In another case cylinders in cast iron compressor blocks had to be "corrected" by sleeving operations in the bore because the foundry did not maintain satisfactory surfaces in the cylinder castings. Good quality control in the process at the foundry eliminated the unnecessary sleeving of cylinders.

Quality control as a system can bring these unnecessary operations out in the open where they can be examined and eliminated. This really is a by-product of quality control. Normally, quality control is thought of as a system of "Inspection, Analysis, and Action"... to maintain the desired level of quality. (From Copyright Definition of Quality Control, Westinghouse Electric Corporation) It might be stated that quality control is an industry that chiefly is concerned with maintaining quality.

Practically every industry has its by-products. For example:- Years ago when a steer was butchered it was butchered for the meat and hide. No thought was given to the possible commercial value of waste products. They were just something to get rid of. Today, in a modern meat packing plant all of the "spare parts" of the butchered steer are used. They are an important part of the profit of the industry.

The quality control "animal" produces the "meat and hides" by maintaining the desired level of quality. Some of the "spare parts" that are left over provide the basis for elimination of unnecessary operations. There is in the "spare parts" this by-product that may mean a great deal in the country's effort in defense mobilization.

To see how this profitable by-product is possible, it is advisable to first examine the way quality control works. Quality control skillfully planned analyses inspection data gathered from manufacturing

operations to determine two important characteristics at every step of the manufacturing process. Analysis of the inspection data should determine the average quality that is being produced and the amount of variability in quality. This, in other words, means determining the limitations and capabilities of every step in the manufacturing process with respect to that which is desired by the specifications for quality.

Quite often when each step in the manufacturing operation is evaluated and the average quality and variations in quality are determined, some specific operation can be eliminated because an operation before or after that operation is quite capable of producing all that is required from a quality standpoint.

The small motor rotors that were briefly mentioned is a good example where a manufacturing operation was eliminated. Rotors at the rate of 2500 per day were machined to meet the specification requirements for quality on the diameter to $\pm$ .002". The rotors were machined by first taking a roughing or "qualifying cut" in one turret lathe and then taking a finish cut in a second turret lathe.

The rotors were inspected after the finishing operation by using a Go and No Go Gage. The roughing or "qualifying" operation was inspected in a similar manner. Records were not maintained of the number of times inspection was performed, or how often unsatisfactory quality was being produced that required corrective action. Apparently, however, the number of rotors that were defective was small.

Because the defectives were negligible, it should not be concluded that quality control has done a good job. A good quality level has been maintained in this instance, but not because of quality control. It is like the old horse that pulled the milk wagon. No one guided him; he just got there because he had been there so often.

The success of quality control depends upon expert analysis of inspection data. Before a good analysis can be had that will correctly determine the average quality and variations in quality of every operation, there are certain requirements that must be established. There must be:-

(1) Sufficient amount of inspection coverage.

(2) Proper tools and gages available.

(3) Adequate records.

The requirements should be explained in detail because they are so important to good quality control. Rather than treat them in a formal manner, they will be explained by several examples in which they apply.

These requirements are not met in the example of the rotors. There may have been enough inspection coverage of the rotor turning operation, but the Go and No Go gages are inadequate for measuring accurately the desired quality, and there aren't any records to show what quality had been produced in the past.

There should be gages capable of measuring quality sufficiently accurate enough to determine the average diameter and the amount of variation around the average diameter. In this case it was necessary to obtain a dial gage capable of measuring to .0001".

An Average, $\bar{X}$, and Range, R, chart was established on both the roughing or "qualifying" cuts and the finish cut. Inspection was performed periodically with the dial gage and the results of the inspection recorded on the average and range control chart. Having satisfied the requirements in this manner, it was possible to make a good analysis of rotor turning.

The control chart at the roughing, or "qualifying" cut disclosed that the roughing cut was capable of maintaining $\pm$ .0015" on the diameter of the rotors. An adjustment was therefore made to the roughing lathe in such a way as to produce an average diameter that was the same as the specification nominal. Since the analysis indicated that the "qualifying" lathe could produce to $\pm$ .0015" it can be seen that all rotors will fall within the $\pm$ .002"as required. Therefore, the finish operation is unnecessary and it was eliminated.

The average and range control chart on this operation was all that was required to maintain the desired level of quality. The savings amounted to approximately $500.00 per month. The turret lathe used for finish turning was made available for other work and manpower was used more effectively.

The rotors provided a more simple example than is usually the case. There were only two machines involved in a simple machining operation. The entire problem was solved within the machining area. Quite often, a part is made in one area and then is moved to another area where a "qualifying" operation is performed.

Motor brackets produced in the foundry and then shipped to a machine shop for machining is an example of this kind of product. Approximately 5,000 brackets are produced each day at the foundry. This requires several patterns in operation simulatenously to produce the required number of brackets. The hub diameter of the brackets is "qualified" in the machine shop to permit chucking for subsequent operations, and also to make possible the assembly of a mounting ring. The hub diameter must be held to $\pm$ .0075 inches as is shown in the sketch of the bracket in Figure A.

Each pattern must be considered, as far as quality control analysis is concerned, as a separate manufacturing operation. Castings from each pattern should be inspected to determine the average diameter and the variation around the average diameter of each pattern.

It has often been stated that one should not expect to measure castings with a micrometer. However, a micrometer was used for measuring these castings for the purpose of determining how close sand castings could be consistently cast on a conveyor line production basis.

The patterns are metal, and there were eight patterns in use simultaneously. Twenty-five castings from each pattern were measured, making a total of 200 measurements. From these observations, the average and standard deviation were calculated, and from this information,

frequency distribution curves were plotted as shown in Figure B.

Then all of the 200 observations were thrown together and the average and standard deviation of the 200 observations calculated. The frequency distribution curve shown at the left in Figure B was drawn. This frequency distribution shows what the machine shop received as compared to that which is desired. From this curve of all patterns together, it can be seen that the machine shop was receiving castings, the hub diameter of which varied from 1.816 to 1.848 inches. There is a variation of approximately ± .016 inches, therefore requiring a "qualifying" operation on the hub.

Examination of the individual patterns demonstrates that in no case is the total range in any one pattern greated than .014 inches or ± .007 inches. This means the foundry can make these castings within a total tolerance of ± .007 inches; but it will be noticed that the average of the pattern producing the smallest hub is 1.824 inches, and the pattern producing the largest hub is 1.840 inches. While there is a difference of only .014 inches between the smallest and largest hub produced in any particular pattern, there is a difference of .016 inches between the average of the largest and smallest patterns. Stated statistically, there is a greater variation from pattern to pattern than there is between patterns.

The quality control analysis resolved the problem into one of making the patterns within closer tolerances. Since these were metal patterns, this was not a difficult task. Correction of the patterns reduced the variation between castings and the machine shop was not required to "qualify" the hub. The operation was eliminated, resulting in substantial savings in manpower and money.

Desired quality is maintained in the foundry by using a simplified control chart that shows, by pattern, periodic measurements of the patterns.

The collection and analysis of data to solve a quality problem may take much more time than either of the two examples already discussed. Some manufacturing processes may be rather complex, involving a great many relatively unstable variables. The time consumed between manufacturing operation may be weeks or even months. Such is the case in the manufacture of air conditioning compressors.

The cylinder block castings for the compressors that are produced in the foundry are machined in a machine shop and then assembled into a compressor and tested. The time between casting of the block to finish machining may be several months. If a casting is porous in the cylinder bore due to imperfect foundry work, the difficulties may not be determined soon enough to make necessary corrections in the foundry. A "corrective" operation in the machine shop is necessary. Every cylinder that is porous or fails test because of unsatisfactory surfaces must be sleeved.

Several years ago when this problem became acute, there were approximately 150 castings averaging six cylinders per casting produced each month. More than 25% of the approximately 900 cylinders per month had to be sleeved at a cost of almost $15 per cylinder. This makes a total of approximately $3375 per month for "corrective"

sleeving of unsatisfactory cylinders.

The problem for the foundry to improve the castings required the collection of data through inspection, both in the foundry and in the machine shop.

Analysis by the use of average and range control charts in the foundry disclosed instability in the chemical content of cast iron. The average chemical content and the amount of variation in chemical content were both unstable from one casting to the next. This instability could have tremendous influence on the surface conditions of the cylinders. It was necessary to institute more uniform methods of cupola operation. New automatic charging equipment was installed. Also, better raw materials such as coke and scrap iron were bought to reduce instability and improve the chemical content to a satisfactory level. The control charts on chemical content have remained in use and are in use at the present time.

The temperature of the molten metal poured into cylinder block molds was thought to have an important influence on the quality of cylinder surfaces. However, it was not possible to accurately measure the temperature to determine how it varied from casting to casting. It was therefore necessary to develop a satisfactory gage capable of measuring quickly and accurately the temperature of molten cast iron. An immersion tungsten graphite thermocouple was developed in the foundry that is accurate and is capable of measuring temperature within $\pm 10^{\circ}F$. The best temperature for cast iron in this casting was determined and maintained by use of the tungsten graphite thermocouple.

Chemical content and temperature were two variables that were suspected of bringing about erratic results from one casting to another. The quality control charts on chemical content and the temperature control using the tungsten graphite thermocouple have established stability in these two variables. The foundry operation became relatively stable and any significant changes that might be reflected in the castings were the result of some designed corrective action taken to improve the quality of the castings. A way of identifying castings with the conditions under which they were produced became necessary. Otherwise, it would be impossible to know what changes were beneficial and what changes were harmful.

Every casting was identified to show the heat number, the chemical composition, and the temperature of the molten metal as poured into the mold. The identification was maintained on each casting all the way through the machine shop. Before a "corrective" or sleeving operation was performed in the machine shop, the defective area in the casting was identified and reported to the foundry. Photographs were taken in the machine shop of the defective areas and these photographs were used in the foundry to determine the reasons for the defects to thereby prescribe corrective action.

In addition to the work done in the machine shop by identifying the defective areas in the casting, the foundry selected castings and machined them at the foundry. This departure from usual form was most helpful in determining reasons for defects. The time lag between foundry and machine shop was reduced thereby making possible more rapid improvement.

It was possible, having the information concerning chemical content, temperature data, and machine shop data, to properly analyze the problem and make changes in the foundry. A great many of the changes made were in the molding technique. Well placed chill blocks and equalizer blocks and improved gating are the kind of improvements in molding that were made at the foundry. Each change was followed very closely through the machine shop to determine the effectiveness of the change.

After the improvements and changes resulted in better quality castings, a process specification was written that very clearly described every step required in casting these cylinder blocks. This process specification has become a most valuable asset in maintaining the quality of the cylinder blocks.

The number of cylinders that require sleeving at the present time is practically negligible. The costly "corrective" sleeving operation has been virtually eliminated. There has, therefore, resulted in this case tremendous savings in dollars, equipment and man hours.

These several examples have shown where quality control has resulted in the elimination of certain unnecessary manufacturing operations. There has been in every case a certain amount of inspection coverage of every step of the manufacturing operation. In some cases, the inspection was periodic, but not too frequent. In other cases, it was necessary to institute rather detailed inspection of practically every part produced. There had to be a sufficient amount of inspection coverage to obtain data that would make it possible to determine average quality and variations in quality.

When gages were not sufficiently accurate to measure and determine average quality and variations in quality, new gages were obtained. Often, as is demonstrated in the last example, it is necessary to develop new gages to meet the requirements of quality control.

Adequate information was recorded in every case to show what quality had been produced in the past, what quality was being produced at the present, thereby providing a basis for determining what is likely to be produced in the future, and for making a comparison between present quality and past quality. These records are usually simple as in the average and range control charts or frequency distribution analysis records. However, some records may be more detailed as in the cylinder block example and may cover long periods of time.

When the requirements of a good quality control program are met, it is not uncommon to reap important benefits such as elimination of unnecessary operations.

1/4 HORSE POWER MOTOR BRACKET

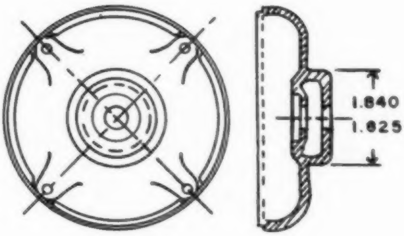


Figure A.

FREQUENCY DISTRIBUTION OF OUTSIDE DIAMETER MEASUREMENT
HUB DIAMETER OF 1/4 H. P. MOTOR BRACKET

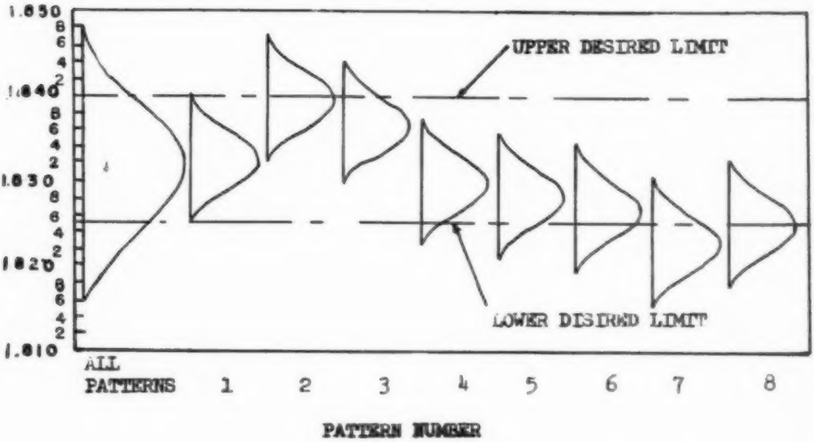


Figure B.

QUALITY CONTROL SIMPLIFIES PRODUCTION PLANNING AND CONTROL*

E. H. Mac Niece
Johnson & Johnson

The production planner always has two unpredictables with which to contend. Even though he has placed purchase requisitions for the right raw material to be delivered at the right time, there is always a chance that the raw material will be unsuitable for production when it arrives. His production schedules may also correctly provide the needed quantities only to have some portion of them lost because the product fails to meet quality standards.

Until shortly before World War II, these two factors gravely reduced the accuracy of production planning. Then, under the stimulating leadership of Dr. Walter A. Shewhart, and because of the demand for increased production, industry rapidly adopted statistical quality control. The beneficial results were manifold but this paper is concerned with those that have helped to simplify production planning and control.

Quality control, reduced to its simplest terms, is the control of quality during the manufacturing process. It detects the causes for variations in product characteristics and corrects them. It is economic in its purpose, objective in its procedure, dynamic in its operation, and helpful in its treatment of operating difficulties. Since variations in raw materials have marked effects on the quality of in-process materials, quality control includes statistical sampling and testing before acceptance. It also includes the examination of quality characteristics in finished products, as an overcheck on the in-process controls and for the purpose of assuring satisfactory outgoing quality.

Both quality control and inspection are used to assure quality. Inspection is a sorting process that classifies materials, parts or products as acceptable or unacceptable. As control becomes effective, the need for inspection decreases.

To measure every piece of incoming material, or to run chemical or physical tests on every drum of chemicals and every bolt of cloth received, would require a receiving inspection force almost as large as manufacturing force itself. Inventories would have to be increased to allow time for detailed inspection and testing. It is here that scientific statistical sampling can be used to prevent acceptance of unsatisfactory materials quickly and at minimum cost. Although savings in cost are very important, the speed with which results are obtained often means the success or failure of the production plan. If, for example, a raw material is received today and found to be defective tomorrow, the purchasing department will have a week or more in which to obtain a replacement. If this is impossible, the planner will at least have time to devise an alternative plan for production.

The most popular sampling plans are based on the Dodge-Romig Tables for single and double sampling. All these plans are designed for

* Most of the material in this paper is from "PRODUCTION FORECASTING, PLANNING AND CONTROL", by E. H. MAC NIECE, JOHN WILEY and Sons, Inc., 1951 and is reprinted by special permission of the publisher.

simplicity, speed, and economy. The sample size is a function of the lot size under consideration. The ratio of sample size to lot size diminishes with increasing lot sizes, yet it constantly maintains a stipulated protection.

The Statistical Research Group at Columbia University developed a sequential sampling plan used by several divisions of the armed services during World War II. Under this plan, additional samples must be tested as long as the number of defectives falls between the acceptance and rejection numbers. In the seventh or eighth trial the acceptance and rejection numbers become consecutive, thus forcing a decision.

Recently the Department of Defense released MIL-STD-105A which presents tables for single, double and sequential sampling. Because these tables will be used extensively by the armed services and industry, suppose we examine an example showing how they work.

Let us assume that a certain part is to be used in an assembly operation. If no more than 2.5 per cent of these parts are defective, assembly will not be delayed or stopped, since the defective parts can be cast aside by the assemblers. The supplier's price and the producer's costs have been based on this percentage.

Let us further assume that 3,000 pieces of this part are received in a specific shipment. Inspection records show that the supplier's process average defective has been 1.5 per cent.

Referring to MIL-STD-105A, Table IV-A for single sampling, we find that if a sample of 150 pieces drawn at random from the shipment contains 8 or less defective pieces, the shipment is accepted. If the sample contains 9 or more defective pieces, the shipment is rejected.

Since the supplier's process average has been 1.5 per cent, it is reasonable to assume double sampling with a smaller first sample might result in a quicker more economical decision. Referring to Table IV-B in MIL-STD-105A for double sampling, we find that if a sample of 100 pieces contains 5 or less defectives, the shipment is accepted. If it contains 12 or more, it is rejected. If it contains more than 5 and less than 12, a second sample of 200 additional pieces are drawn from the shipment. If the sum of the defectives (300 pieces) found in the first sample (100 pieces) and the second sample (200 pieces) is 11 or less, the shipment is accepted. If 12 or more defectives are found, the shipment is rejected.

Multiple Sampling can also be used in this example and may result in a less expensive decision, if the quality of the shipment is better or worse than the acceptable quality level. The following factors from MIL-STD-105A, Table IV-C, can be applied using the same information assumed in our example:

Sample	Sample Size	Cumulative Sample Size	Acceptance Number	Rejection Number
First	40	40	0	4
Second	40	80	2	7
Third	40	120	5	9
Fourth	40	160	7	11
Fifth	40	200	9	13
Sixth	40	240	11	15
Seventh	40	280	15	16

If in the first 40 pieces tested no defectives are found, the shipment is accepted. If 4 or more defectives are found, the reject number is reached and the shipment is rejected. If there are 1, 2, or 3 defectives, a second sample of 40 must be tested. If the cumulated defectives in the 80 pieces of the combined first and second samples are 2 or less, the shipment is accepted. If the defectives are 7 or more, the shipment is rejected. If there are 3, 4, 5, or 6 defectives, a third sample is tested, and so on until proper action is indicated.

In the reorganization of a business a number of years ago, one of the first considerations was the establishment of an adequate arrangement for production planning. Operations were typically primary, or machining, and secondary, or assembly. Raw-stores and finished-goods inventory controls proved to be effective soon after their introduction. The assembly department consistently failed to meet its schedule, and finished-parts stores inventories failed to balance. An analysis showed that many of the finished parts were nonconforming. To reinspect all the parts in stocks would have been expensive and, moreover, would have slowed up the whole program. Because no statistical sampling plans were available at that time, the problem was solved by an ingenious method. Small random samples of each part were selected in 5 groups. If the variation in the cumulative average of the per cent defective of the fifth group did not vary more than ± 5 per cent from the cumulative average of the first 4 samples, the average of the 5 samples was considered to be the per cent defective for the particular part in question. If the variation was greater than ± 5 per cent, additional small samples were inspected until the variation did not exceed ± 5 per cent.

The whole production planning was revised to allow for the defectives as estimated by this empirical method of sampling. Though the final results were far from perfect, the production planning was converted from a basis of certain failure to one that saved the life of the reorganization. Fortunately such crude treatments need not be resorted to today. Sampling plans proved by millions of trial applications are available for industrial use.

In the past production planners found it extremely difficult to include material shrinkage allowances in their estimates of gross material requirements. This was once done by rather rough guessing. Today quality-control engineers have accumulated useful backgroud information from the study of process capabilities. For example, if a dimension is to be held within a tolerance of ± 0.001, the quality - control engineer knows that about 20 per cent of the pieces produced on an old-type milling machine will not meet specification, though the figure for a modern machine will be approximately 1 per cent. If a specific machine is under consideration for production, the engineer

therefore can predict its process capability within narrow limits of accuracy. For a cloth of given specifications, the percentage of defective material will be considerably reduced if modern looms are used instead of older ones. In coating and spreading operations, process capabilities determine the yields from given quantities of raw materials. Suppose, for example, that an old paper machine must be used to produce sheets having a basis weight of 30 pounds ± 0.5 pound. Because of limitations in process capability, it may be necessary to run on the high side so that sheets will not fall below the minimum of 29.5 pounds. The pulp consumption therefore will be considerably greater than that computed on a theoretical basis without regard for the process capability of the machine to be used.

Figure 1 shows the process capabilities of three coating machines that are to be used in producing a single item. The coating compound is expensive, but a minimum of 2.6 ounces must be used on every square yard. Figure 2 shows that on machine A the average weight of compound will be 2.74 ounces per square yard. With machine B it will be 2.83 ounces, and with machine C, 2.95 ounces.

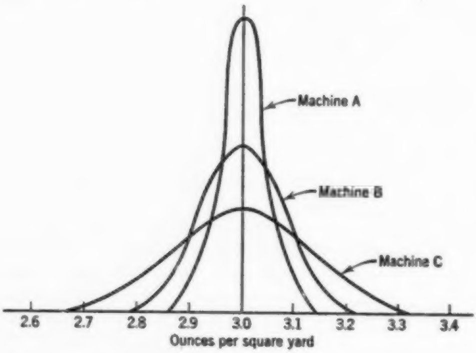


Fig. 1 Process capabilities of these coating machines

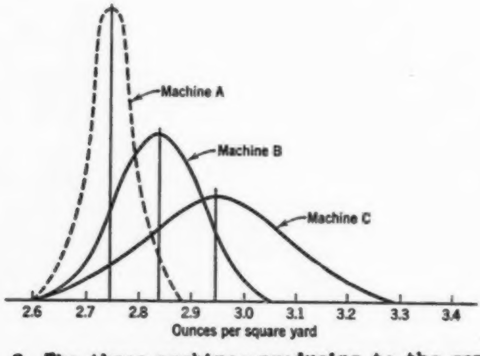


Fig. 2 The three machines producing to the same minimum coating weight

This simple analysis of process capabilities discloses five other facts of vital importance to the planner:

1. Raw-material requirements will vary, depending upon which machine is used for production of different items or the same items at different times.

2. Products requiring the most expensive coating material should be produced on machine A; the next most expensive on B, and the least expensive on C.

3. If the same objective average weights are used on all three machines, a large percentage of production from machines B and C will not conform to specifications.

4. Machines B and C should be examined to determine whether they can be repaired or modified to equal the performance of A.

5. If repair or modification will not produce the desired results, production costs should be reviewed with care. They may show that machines B and C should be replaced with new ones.

The manufacturing planner and the production planner will be wise to work in close cooperation with the quality-control engineers, first, to learn what inputs of materials are required for given outputs, and second, to discover the need for new equipment when the old will not perform well or profitably.

The whole purpose of quality control is to maintain product dimensions and other characteristics within specifications during the manufacturing process rather than to report failure after things have been made. Where control is effectively used in a continuing sequence of manufacture, test, adjust, the production planner's work can proceed in a straightforward manner. He will, however, wish to maintain effective lines of communication with the people in quality control. Even in the best-run factories there will be times when certain processes get out of control, and the production planner will need to know the extent of each difficulty. If certain quantities are irreparably lost to production, or if the nonconformance to specifications requires rework, he must adjust his plans accordingly.

Figure 3 shows a typical per cent defective quality-control chart. As long as the percentage of defectives remains below 2, there is no difficulty in subsequent assembly operations. Planned cost and outputs also are achieved. Excellent control was maintained until the eighteenth of the month, but most of the work produced on the eighteenth and nineteenth day had to be sorted on a 100 per cent testing basis. Production planning had a 5-day lead, and there was no disruption of the planning other than to replan for the defectives scheduled for repair. If the high rate of defectives had continued for 3 days more, however, the production planner would have had to substitute some alternative planning.

In the manufacture of many types of consumer goods the control of weights and measures is essential to the control of costs and quantities of material used. As an example, filling 1-pound cans of coffee requires control of weight. If the ordinary process of filling maintains a weight of 1 pound ± 5 per cent, the company may set its weighing machinery to fill at 476 grams, a pound being 453.6. This guarantees that requirements of the Food and Drug Administration will not be violated. Individual weights will vary between 454 and 499 grams. The average outgoing weight will be 476 grams, or 1 pound + 5 per cent.

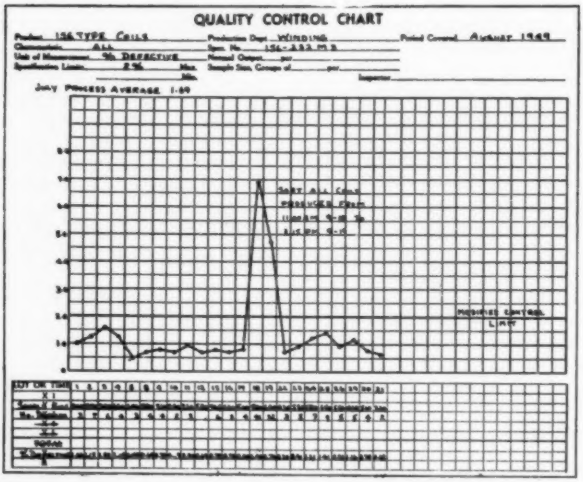


Fig. 3 A typical percent defective chart

Control charts may reveal factors the elimination of which will permit maintenance of control within ± 1 per cent. The objective weight can then be set at 458 grams. Aside from establishing a competitive advantage by eliminating overages, quality control focuses attention upon subsequent production so that weights and measures are maintained with essential accuracy.

To be effective in its own sphere, and to stabilize production planning, quality control must concentrate its attention upon processes while they are in operation. It is essential that samples be examined before any defectives are removed. This permits an appraisal of process quality levels so that corrective action can be taken when it is needed.

Quality control is vitally important in the process industries because sorting is economically unsound. Most testing is destructive. To apply destructive tests on a 100 per cent basis would destroy all the product. Such a method might be of academic interest but would be economically fatal. As an example, the best test for a shot gun shell is to shoot it. After you have shot it nothing is left except the test results.

A chief inspector in a machine shop recently complained that, though fine for the process industries, statistical quality control could not be applied in a machine shop. There were several tote pans of machined parts near a machine, each pan containing about four thousand parts. The inspector was asked if he would be willing to release a particular pan without one hundred per cent inspection if not more than ten pieces out of 305 were found to be outside specification limits. After some deliberation he replied that this would result in a probable two per cent culling in assembly and that this was not unusual even when every piece had been inspected. Yes, he would be willing to release a pan on that basis.

Periodic sampling at the machine was then suggested, with the understanding that 100 per cent inspection would be resorted to only when charts showed the process to be out of control. Small samples appealed to the inspector because they would cut inspection costs to a minimum. Control was even more appealing, since it would permit adjustments as the process continued.

Many new high-speed automatic production processes have been introduced since 1940, and they have forced a change in the thinking of management. In the past, conscientious efforts were made to produce large quantities of goods and then to achieve quality assurance by sorting the good from the bad. As we have said, this was both costly and unreliable. Persons responsible for production planning could never be sure of net production until too late for any reasonable degree of control. Production costs were uncertain. Finally, if inspection and attendant sorting were not much more accurate than the processes of manufacture, many defective articles went to dealers and consumers.

Variations are inevitable in any industrial process. Economics, moreover, dictates that variations should be accepted within limits that are consistent with a product's intended use. An examination of quality determinations from controlled processes will generally show a normal frequency distribution like that of Figure I.

Individual measurements and test results are not well adapted to the purposes of analysis and control. Charted averages and ranges of subgroups of 3, 4, or 5 measurements or test results are extremely sensitive indicators. As an example, assume the following periodic measurements of viscosity:

Sample 1 = 135.0 seconds
Sample 2 = 134.9 seconds
Sample 3 = 135.0 seconds
Sample 4 = 136.8 seconds
Sample 5 = 136.7 seconds

5) 678.4

135.7 = average seconds
1.9 = range (difference between largest and smallest value)

The foregoing average and range values appear as the first points on the chart forming Figure 4. This chart also plots 25 other averages and ranges, which establish control limits of 133.3 to 137.1 seconds for averages and 6.9 seconds for ranges.

During subsequent production, variations in averages or ranges that lie within the control limits may be confidently attributed to chance combinations of variables inherent in processes and equipment employed. Trends that transcend these limits reveal the introduction of variables abnormal to the controlled process and also indicate their causes, so that remedial action can be taken. As an example, the chart in Figure 4 shows 5 consecutive increases in viscosity from lot 148 to lot 153. If corrective action had not been taken with lot 154, the process would have wandered outside its own control.

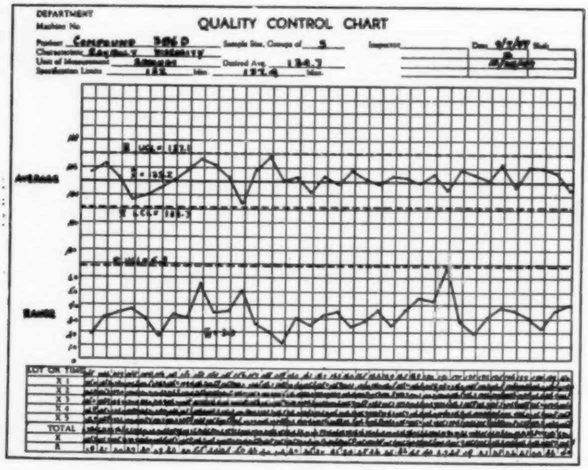


Fig. 4   An average and range chart

When values for quality characteristics are charted and adjustments made to maintain their control, and, when per cent defective charts reveal process quality levels that demand only occasional sorting based on calculated risks, their assurance of high levels in outgoing quality is excellent. With assurance of both process and outgoing quality, planning and control of production become simple and reliable.

SUMMARY

Quality control uses statistical methods to overcome the two great unpredictables of planning. It indicates when losses impend because of nonconformance to standards of quality. It gives prompt notice when incoming raw materials do not meet specifications. Basing its computations on supplier and process capabilities, quality control also provides reliable estimates of material and product losses.

Statistical sampling of raw materials now provides reliable information quickly yet uses relatively small samples to represent large lots. The time interval required for receiving inspection is reduced so that raw materials promptly become available for production.

In processing, quality control avoids the production of large quantities of goods that would later prove to be unacceptable. The sequence of manufacture-test-adjust, frequently repeated, provides good control and assurance of quality. It minimizes losses from material overages by exercising effective control over weights and measures. Quality control also simplifies planning and scheduling by keeping returned goods at the minimum and so reducing the problems of replacement.

APPLICATIONS OF SEQUENTIAL SAMPLING IN RECEIVING INSPECTION

Edward R. Close
Bausch & Lomb Optical Company

Despite the number of sampling plans which had been developed by 1947 it was not a simple matter to decide upon a set of sampling tables which would have a broad general application in the Instrument Division of Bausch and Lomb. The difficulty in making this decision was due primarily to the wide variety of sales items manufactured and the production quantities involved. There are approximately 2300 different sales items involving over 38,000 component parts and optics. The production quantities range from a low of 25 per year to a high of many thousands per year.

The problem of selecting sampling tables which were readily applicable in receiving inspection was accentuated by the difficulty in obtaining information regarding the suppliers process average. Many items are ordered from suppliers in quantities of only a few hundred once or twice a year. If sampling was to be applied to these items, one could not wait until sufficient control chart evidence had been accumulated to determine the process average before deciding which sampling plan to use. We had to make a decision with the information available at the time.

While information regarding the suppliers performance was generally meager, there was ample information upon which to base decisions as to what constituted acceptable and unacceptable quality. When the acceptable and unacceptable quality levels were determined in terms of percent defective and associated with their appropriate risks, a sequential sampling plan was defined. Thus we were led, quite naturally, into the choice of sequential sampling for inspection by attributes.

Due to the infrequency with which many items are received for inspection, the decision as to which sampling table to use depends upon the inspection supervisors ability to analyze the requirements of the item in question. He must choose a sampling plan with an operating characteristic curve which gives adequate protection against accepting lots of material which do not meet these requirements, and administer the sampling procedure so that in the long-run the calculated risks will be maintained. This calls for an inspection supervisor who is well grounded in engineering know-how and who has a sound background in the technical aspects of sampling.

The sampling tables shown in Fig. 1 were developed to cover five quality levels which could be applied to the great majority of the items received. In order to minimize the amount of inspection values of p_1 and p_2 were selected such that the difference between them was as great as possible. For each quality level, three types of sampling tables were provided. The tight sampling plan minimizes the risk of accepting bad lots. The normal sampling plan has a risk of .10 of accepting bad lots. The reduced sampling plan has a risk of .50 of accepting bad lots and is used only when there is ample evidence that the suppliers process average is such that it is highly unlikely that a bad lot will be presented for inspection.

QUALITY LEVEL		SEQUENTIAL SAMPLING TABLES														
		A			B			C			D			E		
		P_1 = .25% P_2 = 1.5%			P_1 = .5% P_2 = 3%			P_1 = 1% P_2 = 5%			P_1 = 2% P_2 = 8%			P_1 = 3% P_2 = 10%		
TYPE	S.N.	S S	A	R	S S	A	R	S S	A	R	S S	A	R	S S	A	R
I	1	234	0	4	116	0	4	72	0	4	47	0	5	40	0	5
Tight	2	143	1	5	71	1	5	40	1	5	23	1	6	17	1	6
A = .05	3	143	2	6	71	2	6	40	2	6	23	2	7	17	2	7
B = .05	4	143	3	7	71	3	7	40	3	7	23	3	8	17	3	8
	5	143	4	8	71	4	8	40	4	8	23	4	9	17	4	9
II	1	179	0	3	89	0	3	55	0	4	36	0	4	31	0	5
Normal	2	143	1	4	71	1	4	40	1	5	23	1	5	17	1	6
A = .05	3	143	2	5	71	2	5	40	2	6	23	2	6	17	2	7
B = .10	4	143	3	6	71	3	6	40	3	7	23	3	7	17	3	8
	5	143	4	7	71	4	7	40	4	8	23	4	8	17	4	9
III	1	51	0	2	26	0	2	16	0	2	11	0	3	9	0	3
Reduced	2	143	1	3	71	1	3	40	1	3	23	1	4	17	1	4
A = .05	3	143	2	4	71	2	4	40	2	4	23	2	5	17	2	5
B = .50	4	143	3	5	71	3	5	40	3	5	23	3	6	17	3	6
	5	143	4	6	71	4	6	40	4	6	23	4	7	17	4	7

Figure 1

The sample sizes were chosen such that good lots would be accepted with the least amount of inspection. This was done under the philosophy that a large majority of the lots received are of acceptable quality and in the long-run tables so made will minimize the total amount of inspection.

The successful operation of these sampling plans depended largely upon the ability of the inspection supervisor to select the correct table and to make sure that the inspectors followed proper procedures in the selection of random samples of the designated size, and accepting or rejecting lots when the appropriate number of defects were found. To make sure that the people responsible for the operation of the plan were familiar with sampling theory and procedures, an in-plant training course of 10 hours of classroom instructions was given to 30 supervisors and key inspectors. This training course covered the following:

1. A general background in sampling theory involving bead experiments, making O.C. curves for single sampling plans and definition of terms, AQL, AOQL, Lot Tolerance Per cent Defective, etc.

2. A brief discussion of the theory of sequential sampling plans and classroom practice in making up a sequential chart.

3. Discussions which stressed the administration of sampling procedures such as (1) the importance of selecting random samples, (2) the necessity for following the procedure exactly, (3) the keeping of inspection records and (4) the risks involved in going to reduced sampling.

It was only after this course had been completed that the sequential sampling plans were put into operation.

One of the many items sampled are crown glass squares which are purchased in quantities of approximately 3000 in each lot. These are squares of crown glass which weigh about 23 grams each. A square which contains a bubble greater than .2 mm in diameter is considered to be defective. The sampling plan used on this item is table D - II which is defined as $p_1 = .02$, $p_2 = .08$, $A = .05$, $B = .10$. The results of inspecting 13 lots of these items are tabulated below.

LOT NUMBER	NUMBER INSPECTED	NUMBER DEFECTIVE	ACCEPT	REJECT
223	59	1	x	
224	82	2	x	
225	59	1	x	
226	128	8		x
227	36	0	x	
228	82	6		x
229	82	2	x	
230	36	0	x	
231	36	0	x	
232	105	5	x	
233	36	0	x	
234	59	1	x	
235	36	0	x	
	836		11	2

The totals in the table show that, in sampling, 836 pieces were inspected. Eleven lots were accepted on the basis of the sample and two were rejected. The rejected lots were inspected 100% to screen out the defectives.

A single sampling plan with approximately the same O,C. curve would have a sample size of 115 and an acceptance number of 5. The use of this plan in inspecting these same 13 lots would require the inspection of 1495 pieces during the sampling procedure and would have resulted in rejecting the same two lots. It might also have resulted in rejecting lot number 232.

In addition to the standard sequential sampling tables, special tables may be tailored to fit the requirements of a particular item. This has recently been expanded to the use of sequential tests for variable measurements.

A specific example of a test for measurements is the sequential chart shown in Fig. 2. The characteristic being inspected is the parallelism of the three pads on the bottom of a die cast microscope base. If these three pads are out of parallel more than .030" they will fail to clean up in a milling operation. In order to salvage them, extra operations and special handling are required through the rest of the machining cycle. On those lots which have a substantial percentage of bases which do not clean up, it is more economical to sort out the defectives and straighten them before putting the lot into work. Thus the purpose of the sampling inspection is to decide as quickly as possible which lots must be sorted and the defectives straightened, and which lots can be processed as they are.

Experience has shown that the standard deviation for this characteristic is consistent within satisfactory limits, at about .005", but that the lot means are subject to variations beyond satisfactory limits. The sequential test selected was a one way test of the average (1) based on the following quantities which define the plan:

An acceptable lot mean	m_1 =	.010"
An unacceptable lot mean	m_2 =	.015"
The process standard deviation	σ =	.005"
The risk of rejecting a good lot	A =	.05
The risk of accepting a bad lot	B =	.10

The results of sampling a typical lot are tabulated below and are also shown graphically on the sequential chart in Fig. 2.

n	ΣX for acceptance	X observed	ΣX observed	ΣX for rejection
1	1.3	5	5	26.9
2	13.8	10	15	39.4
3	26.3	13	28	51.9
4	38.8	12	40	64.4
5	51.3	3	43	76.9
6	63.8	14	57	89.4

SAMPLING PLAN FOR MICROSCOPE BASES

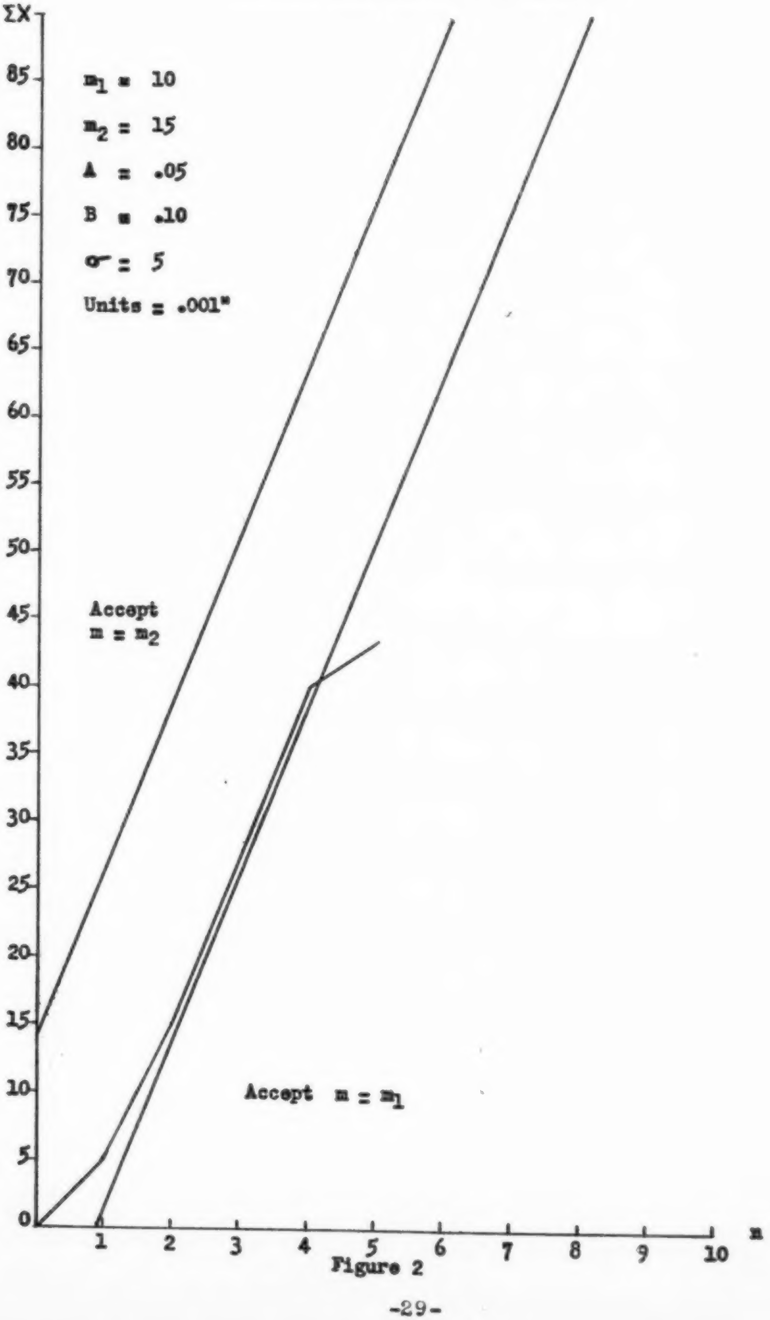


Figure 2

The use of this plan has resulted in a decision to accept or repair microscope bases with an average sample size of 16. Prior to our use of this sampling plan a t-test was used with a sample size of 25. This plan has been in operation for over a year and during this period there have been no complaints from the factory.

The sequential sampling plans have been used in the Instrument Division and Glass Plant receiving inspection since 1947. In the Glass Plant, where 100% inspection had been used, the savings in inspection labor have been in excess of $2500 per month. In the Instrument Division, sampling had been done previously on the items purchased in large quantities, therefore the savings in dollars are not so large. However, the application of sequential sampling to the smaller lot quantities has resulted in a conservative estimate of 25% savings in the total cost of receiving inspection.

1 Sequential Analysis of Statistical Data: Applications
Columbia University Press, New York, 1945

RECENT LOT PLOT EXPERIENCES AROUND THE COUNTRY

Dorian Shainin
Hamilton Standard Division
United Aircraft Corp.

On November 19th, 1947 I presented the first public explanation of the details of operation of the Lot Plot plan before a meeting of the Boston Society for Quality Control. Interest in the plan has been growing steadily. My company has been kind enough to permit anyone to copy our form and use the method. The file of copies of such Lot Plot forms sent to me covers an interesting cross section of industry:

AIR CONDITIONING
York Corp.
York, Pa.

AIRCRAFT
Republic Aviation
Farmingdale, N. Y.

AIRCRAFT ACCESSORIES
Bendix Aviation
South Bend, Ind.

Pesco Products Div.
Bedford, Ohio

Scintilla Magneto Div.
Sidney, N. Y.

AIRCRAFT ENGINES
Allison Div. GMC
Indianapolis, Ind.

Pratt & Whitney
East Hartford, Conn.

AUTOMOTIVE
Willys-Overland Motors
Toledo, Ohio

AUTOMOTIVE ACCESSORIES
Delco Remy Div. GMC
Anderson, Ind.

BRUSHES
Fuller Brush Co.
Hartford, Conn.

BUSINESS MACHINES
Hedman Co.
Chicago, Ill.

I.B.M. Corp.
Endicott, N. Y.

BUSINESS MACHINES
Pitney-Bowes
Stamford, Conn.

Underwood Corp.
Hartford, Conn.

Victor Add. Mach.
Chicago, Ill.

CARPETS
Bigelow Sanford
Thompsonville, Ct.

COUNTERS
Veeder Root Inc.
Hartford, Conn.

ELECTRICAL
The Bristol Co.
Waterbury, Conn.

Collins Radio Co.
Cedar Rapids, Iowa

Delco Radio Div GMC
Kokomo, Ind.

Hart Mfg. Co.
Hartford, Conn.

Silex Co.
Hartford, Conn.

Wagner Elec. Co.
St. Louis, Mo.

FOOD MACHINES
Sanitary Scale Co.
Belvidere, Ill.

GOVERNORS
Woodward Governor
Rockford, Ill.

HARDWARE
Allen Mfg. Co.
Hartford, Conn.

Capewell Mfg. Co.
Hartford, Conn.

Lamson & Sessions Co.
Cleveland, Ohio

Standard Pressed Steel
Jenkintown, Pa.

INDUSTRIAL CHAINS
Whitney Chain & Mfg.
Hartford, Conn.

MACHINE SHOP
ExCello Corp.
Detroit, Mich.

Inland Mfg. Co.
Omaha, Neb.

Perkins Mach. & Gear
Springfield, Mass.

PENS & PENCILS
Esterbrook Pen Co.
Camden, N. J.

PLUMBING
Crane Co.
Chattanooga Div.
Chattanooga, Tenn.

POTTERY
Shenango Pottery Co.
New Castle, Pa.

PRESSED METAL PRODUCTS
Scovill Mfg. Co.
Waterbury, Conn.

PUBLIC UTILITIES
Sou. Cal. Gas Co.
Los Angeles, Cal.

SPECIAL MACHINERY
Torrington Mfg. Co.
Impeller Div.
Torrington, Conn.

SPRINGS
Amer. Coil Spring
Muskegon, Mich.

Wm. D. Gibson Co.
Chicago, Ill.

Int'l. Spring Co.
Chicago, Ill.

Wallace Barnes
Bristol, Conn.

TEMPERATURE CONTROLS
Revere Corp. of Amer.
Wallingford, Conn.

WASHING MACHINES
Dexter Co.
Fairfield, Iowa

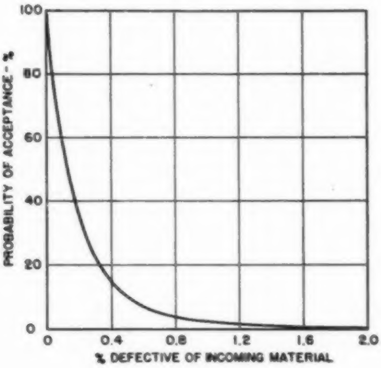
All has not been happy with the Lot Plot -- it has been criticized. It is true that its use at Hamilton Standard has been most effective; several hundred Lot Plots are being made each week in receiving inspection and in the final checking of material fabricated in the plant; it is saving over a quarter of a million dollars each year in inspection wages compared to the previous practice of 100% inspection; and it has cut complaints from the assembly floor and from our customers from a few each month down to a single one in five years of operation. This one complaint was the first instance in the release of over 200,000,000 items by the plan. Any sampling plan guarantees there is a risk involved. The risk is extremely small for the Lot Plot plan but nevertheless it is there. The tremendous improvement in results over those of any 100% or multi-hundred percent inspection plan is of extreme value to us in the aircraft industry where risks must be kept almost to the vanishing point.

Criticisms of the Lot Plot have fallen into four categories:

1) the plan is too tight for most industries
2) its mathematical background is not sufficiently well established
3) several frequency histograms of fifty pieces each from the same lot will not show the same shape of distribution
4) the staggered scale employed on the form is confusing

1) It should be explained that the purpose of the Lot Plot is not to operate in the manner of conventional sampling plans. There, material of a given percent defective will be acceptable a certain percentage of the time and will be rejectable a percentage equal to 100 minus this first percentage in the long run. Also the Lot Plot does not involve screening of rejected lots in order to achieve an average outgoing quality limit. Its purpose is to get as accurate a picture of the condition of the particular lot in question as is humanly and practically possible. A measure of how close the data come to reflecting the condition of the lot, how small the sample error is kept can be seen from the "tight" operating characteristic curve. After you have this near-accurate picture of the lot for each characteristic being checked, then you can use judgment for the individual cases to decide the fate of the lot. It might be accepted as is, a certain minimum number of useable pieces might be found from the lot to be able to continue your assembly operations, or the lot might be returned to the manufacturing source. There its disposition could be scrap, use elsewhere, or a screening in the hope that the number of objectionable defective pieces may be reduced to the extent that the lot will pass another Lot Plot upon resubmission. I do not believe any plant can honestly say that by picking one or several levels of AQL's or AOQL's

or lot tolerances for different classes of material, they are operating as economically as possible. The multitude of specifications, the changing degree at different times of urgency for the use of components, the continual shifting of critical values of certain specifications, as test and service experience is obtained, are all common experiences. These factors make it costly to say in advance, for this part or this group of specifications, we want to set a limit of so much percent defective that we will take in the long run; or that for a given defectiveness we will reject the lots only a certain fixed percentage of the time in the long run.



Operating Characteristic Curve
for Lot Plot Acceptance Plan n = 50

2) Although they are unusual, the irregular distributions of certain samples make it quite a chore to establish confidence limits, unless you plan to gain nothing mathematically from the distribution itself. The methods for analyzing such things as skewed distributions and those with a kurtosis greater or less than plus three were designed to give an estimate of the lot limit position in each case that is either so close to the true position that it will not affect the disposition of the sampled lot, or else it will be in error in a conservative direction (1). Thus it was possible to bring the method of analysis down to where anyone who can read a micrometer can be taught in less than a week to analyze Lot Plots completely.

3) The shape of the distribution of the sample of 50 items will not always reflect the shape of the distribution of the lot. The sampling error of the number of items found by chance in each of the cells of the distribution has only a minor effect on the final results. Close control is maintained over the sampling error involved in the estimation of the mean and of the standard deviation. Noticeable changes in the shape

of the distributions of samples alter the method of analysis employed for each. The result from such samples from a single lot should, a very high percentage of the time, then be either so close to the lot conditions as to have no practical effect on final decisions, or so that any errors involved will be in a safe direction.

4) The staggered scale arrangement has been retained on the new Lot Plot form because it correctly shows the cell boundaries. These cell boundaries correspond to markings on the variable type gage. When properly instructed, an inspector will find that he can proceed more rapidly and more accurately to enter results on the form as falling between the certain cell boundaries that he sees on his indicating device as well as on his Lot Plot form. The new form attempts to make this situation clear by showing that the listed values are those of the lines. Any piece must give a measurement that falls between a pair of lines on the gage. If the inspector is in doubt because his pointer is "right on the line" he can then enter his reading either above or below that line. It will make no practical difference to the final results.

Other improvements to the form involve the addition of (1) a blank column for actual indicator or gage division markings when applicable, to facilitate the entering of results (2) notations for vendor coordination as illustrated and (3) the reverse side of the form shows how to keep a process in statistical control with a control chart; an attempt to describe, explain and illustrate the use of sum and range charts. Sum and average columns are eliminated, the calculation of the average now being made by the method described below. This method cuts about eight minutes from the time to complete the inspection.

a. Cut out the column of plus and minus line values from a blank Lot Plot form.
b. Place this column to cover the line values on the Lot Plot so that the zero cell falls opposite the mode or longest horizontal row of entries.
c. Note whether the +1 or -1 cell contains the most readings.
d. Compare the quantities in these two cells by moving the cut column of paper horizontally to the right until the smaller of the two compared rows is just covered.
e. Count the remaining uncovered squares in the partially covered cell row, multiply this count by the cell sign and value, and enter the result at the extreme right side of the grid in that cell row.
f. Repeat using the +2 and -2 cells, and continue until only the zero cell remains.
g. Total the results algebraically and enter the answer opposite "Totals" in the lower right hand section of the Plot.
h. Multiply this answer by 2 and point off 2 decimal places to the left.
i. Enter this result in the ($\bar{\bar{X}}$ =) space.
j. Point off from the middle of the mode or peak cell row the portions of a cell found by step i, in the direction corresponding to the sign of the i value, and draw a horizontal line labeled $\bar{\bar{X}}$.

(FRONT)
HS F-958D
DATE REC'D. 2-17-48

HAMILTON STANDARD
LOT PLOT AND QUALITY REVIEW ORDER

VENDOR XYZ Co., Rochester, N.Y. PART NAME Retainer PART NO. 55037
P.O. NO. 243524 R.S. NO. 297514 QUANTITY 1400 DATE INSP. 2-17-48
SPEC. .687 $^{+.000}_{-.001}$ O.D. INSPECTOR #32 SAMPLE SIZE 50

VALUE	IND.	LINE NO.	5 · 10 · 15 · 20	
		+10		
.68700	+8	+9	UPPER SPEC.	
95	+7	+8		
90	+6	+7	— — — — — — ULL	
85	+5	+6		
80	+4	+5	1	—
.68675	+3	+4	8 10	—
70	+2	+3	6 6 8	+3
65	+1	+2	1 3 5 5 6 7 9	+2
60	0	+1	2 4 4 5 6 7 8 8 10	+2
55	-1	0	2 3 4 5 5 7 9 9 10 10 — — — $\bar{X}$	—
.68650	-2	-1	1 2 2 4 6 7 9	—
45	-3	-2	1 1 3 3 4 9	—
40	-4	-3	3 10	—
35	-5	-4	2 7	—
30	-6	-5	8	—
.68625	-7	-6	— — — — — — LLL	+7
		-7		x2 / +14
		-8		÷100
		-9		+.14
		-10	LOWER SPEC. (.68600)	

PLEASE!
ASK YOUR OPERATOR TO STUDY THIS DIAGRAM AND—

RANGE	
1	7
2	5
3	5
4	3
5	2
6	4
7	6
8	9
9	4
10	7
11	
12	
13	
14	
15	
ΣR = 53	
3σ = 6.76	
ΣX = +7	
$\bar{X}$ = +.14	

- [ ] MOVE BASIC PRODUCTION SIZE (TOOL SETTING, DIE SIZE, MOLD CAVITY, ETC.) ______ IN ______ DIRECTION
- [ ] REDUCE PROCESS SPREAD AT LEAST ______
- [ ] MAKE THE TWO BASIC PRODUCTION SIZES CENTER AT ______
- [ ] EXPLAIN WHY RED CIRCLED PIECES WERE LEFT IN THE LOT

IF SOME OF THE ABOVE ARE CHECKED, LOOK FOR NEXT LOT PLOT TO SEE IF YOUR ADJUSTMENTS WERE SUCCESSFUL

- [x] ACCEPT OUR CONGRATULATIONS FOR A GOOD JOB! THE OTHER SIDE OF THIS SHEET TELLS YOU HOW TO GET A CHEC.. MARK IN THIS LAST BOX ALL THE TIME

DISPOSITION	
ACCEPT (CO. INSP.)	E. Vernon
Q.R. ACCEPT (HS QR)	
GOV'T. INSPECTOR	T.R.

BEYOND	%	EXTENT
HIGH SPEC.	OK	
LOW SPEC.	OK	

ATTRIBUTE SAMPLE DATA
SAMPLE OF ___ SHOWS ___ PIECES ___

REMARKS—

FACE SIDE OF FORM

HS F-958D(BACK)

SIMPLE PROCESS CONTROL

USING A SUM AND RANGE CHART

Example - Process Specifications - Low Limit = 5 1/2 Units, High Limit = 14 1/2 Units

(12) All control points in example 1 falling within limits indicates desirable controlled condition.

(13) Controlled condition of control points in example 2, within narrower limits indicates improved process. Note smaller difference values in range chart which prompted recalculation of control limits.

(11) Control points in example 3 falling outside limits on both sum and range charts indicate undesirable out-of-control condition. Range point no. 22 and sum point no. 24 warned of impending trouble. Note that no values yet fell beyond specifications. Trouble occurred in samples no. 28, 29, and 30 with three individual values below low specification.

(1) Solid line is average of sum control points. For example 1, total of 10 sums =30+25+30+29+31+33+33+28+31+30=300. Average of 10 sums = 30.

(2) Dotted lines are control limits. i.e. For a sample of 3 values control limits are located from solid line a distance of [3.1] x average range. (See (8)) Example: For example 1, control limits are ± [3.1] x 2.4 = ± 7.4 from solid line. (See (8))

(3) Sums of 3 values in sample

Plotted position of first sum control point is 10+11+14 = 35

(4) Actual item value, such as .011 inch, 11 ounce, or 11 points of hardness on Rockwell scale where 30 R_c might be considered as zero. Measured Value is 31 Rc

(5) Sums of first two values in sample

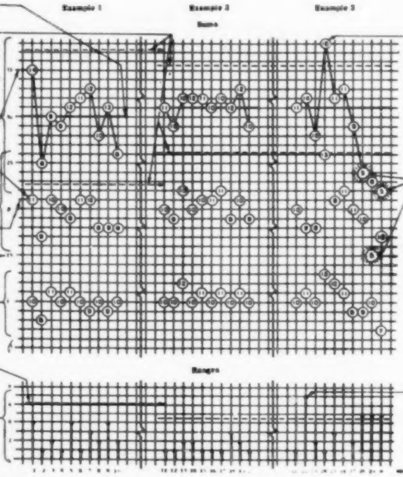
Plotted position of first two values is 10+11 = 21

Scale of values

(6) Values of first item of each sample measured

(7) Dotted line is control limit for samples of 3 values. Control limit is located at value = [2.6] x average range. (See (8)) For example 1, control limit is located at [2.6] x 2.4 = 6.2 from the zero range value (see (8))

(8) Difference between largest and smallest of 3 values in a sample. This difference is called the range. Plotted position of first range control point = 14 - 10 = 4.



Unheeded warning. Action should have been taken. (See (11))

These items are 1/2 unit under low specification !!

(10) Is process capable of, and set correctly to meet specifications? Answer: Take 1/3 of solid line value on sum chart ± [1.8] x distance from the solid line to a control limit, and compare resultant values to specifications. Illustration - For example 1, process limits = (30 ÷ 3) ± [1.8] x 2.4 = 10 ± 4.3 = 5.7 and 14.3. Thus process limits are within specification limits of 5.5 and 14.5 indicating that process is properly centered and narrow enough.

Unheeded warning. Operator did nothing to correct process !!! (See (11))

Sample Numbers for Point Numbers

(9) Example 1
Average of 10 ranges equals the sum of 10 ranges divided by 10
= (4+1+2+1+4+1+3+2+4+2) ÷ 10
= 24 ÷ 10 = 2.4

!! Note !! Items are plotted in order of production. (Manufacturing sequence)

IMPORTANT !!

A. Control limits are boundary lines for sum and range points. Let everything alone when all these points are within control limits. Adjust the process or take other corrective action only when a point falls beyond a control limit. Don't wait - TAKE ACTION IMMEDIATELY.

B. Control limits are calculated as noted above only when ten or more sample numbers are available.

C. Numbers [3.1], [2.6], and [1.8] in boxes are always the same for any process provided three values are used for each sample number.

D. Do not hesitate to write to Hamilton Standard, East Hartford 8, Conn., Attention D. Shainin, Chief Inspector, if any questions arise or if your problem does not seem to be solved by such a chart.

REVERSE SIDE
OF FORM

This summary of experiences brings out some of the psychological as well as material benefits of the Lot Plot.

General comments:
Most of the concerns employing the Lot Plot technique are pleased with the ease with which the picture of each plot can be interpreted by their own inspectors, their suppliers, and their customers. Scintilla Magneto Division of Bendix Aviation Corporation summed up the situation with

"Our experience with the Lot Plot method has shown that its use has wide application. Because the procedure can be easily explained to individuals with little or no statistical background, it is a simple matter to apply the Lot Plot procedure to a variety of situations.

"When the question is raised as to whether a tolerance can be held or not, the Lot Plot never fails to show the true condition existing. The simplicity of the procedure with provision for minimum sampling plus the graphical and mathematical interpretations make an ideal procedure for many types of quality control investigations."

Economy:
While many had general statements on economy the Collins Radio Company reported that they feel the Lot Plot is saving them approximately 40% on direct inspection labor cost, and the Victor Adding Machine Company report a savings in labor cost in excess of $20,000 in the first year of its operation.

Lot Plot finds missing carpet:
The lengths of Bigelow-Sanford Cushionlok carpet rolls are measured by running them on a cylinder and noting the number of revolutions. Each roll of carpet is so marked. An inventory of the lengths sold and those marked on the many rolls in storage fell far short of the total length noted on the original production records. A Lot Plot was made of the rolled out actual lengths of 50 random rolls at a cost of about $8,000. These were plotted as the percentage error of actual minus ticketed lengths (from the cylinder) over the actual lengths. Yes, there was a slippage between the carpet and the cylinder that was not appreciated. The Lot Plot enabled the company to pick the minimum amount of slippage expected in the entire lot and so remark the lengths to recover $16,800 without the danger of a series of complaints from customers about short lengths.

Lot Plots at one plant control quality at another:
The Fuller Brush Company made a Lot Plot of 50 pitch diameters from a shipment of 494,000 threaded pieces. The clear bimodal distribution implied two machines set .002 inch apart, each capable of meeting specifications. The supplier, upon receiving their copy of the Lot Plot, confirmed the conclusion and thanked the company for the information as to the amount each machine had to be reset to make its product acceptable. The brush company says, "We have been using your Lot Plot method for approximately two years and we are more and more amazed each day by the accuracy of this method and the faith we can place in it."

York Corporation's suppliers have expressed appreciation for the Lot Plot analyses they received. Shown clearly was a shipment to shipment

increase in the current needed to develop the required torque, and proof that the cutout time of a motor overload protector had a wider distribution at higher winding temperatures. In turn, York admits that Lot Plots revealed their gages for pressure controls always read 5 p.s.i. higher than their vendor's, and their voltmeter for checking relays was calibrated with divisions that were entirely too coarse.

Production control:

Lot Plots were not designed to replace control charts, but the Scovill Manufacturing Company runs a Lot Plot on each 4-hours' production from each of 10 to 20 machines of a small brass shell that is made in large quantities for numerous customers. Before they inaugurated this plan, they were under fire from their customers. There was too much opportunity for periodic causes of extra variation within machines and shifts among machines. They immediately got out of trouble. "Now, and I knock wood, we have been operating since September 27th 1949 without a single customer complaint."

Both the Pratt & Whitney Aircraft Division of United Aircraft Corp., and the Scintilla Magneto Division of Bendix Aviation Corp., use Lot Plots on successive batches at heat treatment:

at P. & W.

1) To maintain a more constant quality assurance with a decrease in inspection or checking labor.
2) To accumulate data as an aid in establishing optimum time, temperature, and equipment conditions for different alloys and part numbers.
3) To provide data as an aid in reviewing troublesome specifications with Engineering.
4) To provide a basis for more rational dispositions of out-of-specification lots, i.e., correcting entire lot instead of sorting the bad from the good and rehardening them.

at Scintilla-

1) To give the heat treaters a score to shoot at.
2) To minimize the amount of inspection.
3) To reduce wear on expensive equipment.

Pratt & Whitney adds, "The results to date have been very favorable with an average of 200,000 piece-parts being processed monthly." Scintilla says, "The Lot Plot is sometimes a more efficient tool than the control chart for some processes. On high speed, short run jobs where control charts are difficult to set up and administer, the Lot Plot procedure can generally be used efficiently."

The Wallace Barnes Company, Division of Associated Spring Corporation, used a Lot Plot for checking out a pilot run on a new item for one of the Arsenals. The multimodal distribution led to a check with the set-up man. He had made an unnecessary change to the setting because of the results of his measurements on a few pieces.

Willys-Overland Motors, Inc., reports, "We use the Lot Plot very extensively for the analysis of operations as we can determine out-of-control conditions in a manner similar to an $\bar{X}$, R chart."

The high cost of fixed ideas:

The Air Impeller Division of The Torrington Manufacturing Company found, with Lot Plots, that "perfect" balance of fans is more rare than barely acceptable balance, contrary to prior suppositions. It became clear that the operator cannot detect unbalance of a magnitude at all less than the natural tolerance and an improvement in the balancing equipment was needed. From their experiences they comment:

"While the conclusions drawn are obvious in retrospect the fact remains that they were clearly and quickly demonstrated by the routine of the Lot Plot as compared with the alternative methods of non-routine investigation from which conclusions are so often drawn by guesswork.

"We feel that the most powerful argument for the Lot Plot method is that it places in the hands of the inspector a means of determining quantitatively the quality of a lot of material by computations usually no more complicated than those of a bowling score and that in so doing it frees personnel having judgment and experience for more valuable pursuits. Like some theologians who feel that the workings of nature are more wonderful to contemplate than the occasional miracles, we feel that the routine benefits of Lot Plot are more wonderful than its "miracles"."

The Whitney Chain Company detailed several important changes in their operations brought about through Lot Plots, and concluded, "Perhaps some of the things I have reported on would have been corrected without the use of the Lot Plot in other shops. But they had been going on here for fifty years more or less and I suspect we would have talked about it and done nothing for another fifty without the advantage gained from the use of the Lot Plot."

The checking of 60,000 new gas meters per year by Lot Plots is the plan of the Southern California Gas Company. One reason they have not gotten out of the experimental stage in their use of the plan is a difficulty in their own inspection routine disclosed by the Lot Plot plottings.

A hexagon punch for making sockets for a small set screw was found by a Lot Plot to give acceptable results at The Allen Manufacturing Company. The job had been held up for lack of tooling and this particular punch was among those that had been rejected to customary standards.

Versus 100% inspection:

A heavy rolled wire job at the Wallace Barnes Company required 100% sorting because a small percentage continuously fell outside of one limit. Lot Plots located the particular operation that caused the difficulty and indicated the amount and type of correction needed. On their last order for 250,000 parts the Lot Plots showed that only 10,000 parts had to be screened.

The Victor Adding Machine Company found that 100% inspection was now no longer necessary on the thickness of raw strip steel, since they began to use Lot Plots. Also contrary to their specifications for thickness of different lots to different tolerance ranges, the steel often came in to a larger or much smaller spread. The steel is thus classified by the

natural tolerance of the lot for the manufacture of appropriate parts. The plan has also completely eliminated the possibility of over-sized material getting into a blanking operation, which often causes die breakage. It was proved that under the 100% inspection previously used, over-sized stock was overlooked.

The Hedman Company echoes with "When buying in today's steel market we sometimes use a Lot Plot to determine the suitability of a particular lot of steel when a close tolerance on thickness is required."

The extremely close tolerance dimensions on valve stems and on valve tappet rollers at the Pratt & Whitney Division of United Aircraft Corp., have been checked for some time on a daily requirement of over 1,000 pieces of each part. They report "It has been necessary to reject occasional lots of these parts based on Lot Plot results but no assembly difficulties or field service troubles have been reported since the plan was placed in operation. Formerly, 100% inspection was required for each of these drawing requirements; therefore, the reduction in inspection time has been very substantial."

Versus attribute sampling:

The Esterbrook Pen Company reports "There are several items that we purchase in large quantities which when sampled by attributes require a sample of 750 pieces. We now use a sample of 50 using the Lot Plot, and when the sample is rejectable, estimate the percentage not acceptable. A decision is then made as to acceptance or rejection of the shipment. As I said once before - the damn thing really works! Besides economy, the accuracy of sampling by Lot Plot is just as accurate as by attributes if not more so."

The Allison Division of General Motors Corp., ran instruction sessions on statistical quality control for some of their employees and used a lot of 1,000 pieces, with carefully measured and recorded diameters, as a lot from which to draw test samples. The action of single, double, sequential, and Lot Plot sampling was compared. The study included the amount of information obtained with regard to the true condition of the lot and the protection available by each method. Allison concludes its interesting story with "The results of the Lot Plot chart were amazing. Those who had accepted it during the previous session were now willing to accept it with even greater assurance. The two who had been skeptical readily admitted that here was a technique that would be very beneficial to the Inspection Departments. The group was advised that they could not expect the accuracy found in the example each time the technique was used. However, if properly used, they could expect it to give more revealing information than could be obtained from any single, double, or sequential sampling plan."

A happy accident:

Some time ago an attempt was made to demonstrate to the Management of the Underwood Corporation the dependability of this technique. A Lot Plot was made from a lot of 25,190 pieces. The charts which are part of the Lot Plot method predicted from the plot that the lot would contain 10% defective parts. The result of the subsequent 100% sorting proved there was, in fact, exactly 10% or 2,519 parts defective. Their Chief Inspector adds "It so happened that this particular sampling was performed under controlled conditions."

More conservatively, the Delco Remy Division of General Motors Corp., announces, "The actual number of defective pieces found in rejected lots after screening has always been very close to the percentage outside specification limits shown on our Lot Plot Charts."

Influencing customers:

Perhaps it is a characteristic of the spring industry or perhaps it is just another coincidence but two divisions of the Associated Spring Corp., the Wm. D. Gibson Company and Wallace Barnes Company bring out, in turn, "We do use the Lot Plot in quite a few of our processes; however, it is chiefly used in our sampling of outgoing inspection where a copy of the results is forwarded to the customer. We find that this procedure has given us not only a better understanding with our customers, but also, a method by which we are able to compare test results." and "Our experience with the Lot Plot has been such that we place our utmost confidence in its results and readily abide by its decisions. We have also found that in corresponding with customers in regards to changes, etc., reference to the Lot Plot has often been the wedge needed to convince them of our need for increased tolerance."

Also, the American Coil Spring Company says, "We do use your method frequently in making decisions as to disposition of doubtful lots of springs in process and in final inspection. We find the Lot Plot form easier to "sell" than some others we have tried. In two specific cases of different types of parts we were able to get customer's acceptance of previously rejected lots as a result of the use of the Lot Plot form. On the whole we find the Lot Plot plan tells us what we want to know as soon as possible."

Buttons and Bows:

The Shenango Pottery Company complains that when their cups and saucers don't fit properly there is usually a demand for new design for one or the other of the two components. It got to the point with their hotel trade where they were manufacturing 435 different cups and 109 different saucers. The Lot Plot has given them an economical way or recognizing the extent of variation and the percentage of assemblies that will interfere. They are now well on the way to reducing their line by 2/3.

The Scovill Manufacturing Company uses Lot Plots for the acceptance of such diverse items as pearl inserts for grip fasteners, tacks for work garment buttons, and mirrors for cosmetic containers. And to think that the Lot Plot was designed to reduce the risk of defective material getting by 100% inspection in an aircraft propeller machine shop!

(1) "The Hamilton Standard Lot Plot Method of Acceptance Sampling by Variables", July 1950 issue of INDUSTRIAL QUALITY CONTROL.

ANALYZING OPEN HEARTH DATA - STATISTICS vs OPINION

Donald S. Leckie
Republic Steel Corporation

As a result of the rather free interchange of ideas among open hearth operators over the past ten years, plus the shifting around of personnel, the analysis of open hearth operations has become rather stereotyped. One sees just about the same set of records kept in practically all shops of a given type and interpretations of these are almost identical. In addition, the evolution of the traditional methods of analysis of such data has resulted in the almost total reliance on AVERAGES of data. Much confidence has been placed in the somewhat miscellaneous collection of large masses of figures and the computation of their averages. Things are quite comfortable as long as these averages remain where management "thinks" they should. However, these averages seem to have a habit of not staying put, and when they move into a region which someone "considers" too high or too low, things start to pop. The operator is usually at the mercy of these averages, which never tell him what he is doing, but only what he has done.

Fortunately, there are relatively simple methods available for the analysis of such masses of data and which provide much additional information for the guidance of decision. Let us examine a few of these and see what modern statistical analyses can do to eliminate "guesstimation", replace "thinking and considering" with specific and factual answers. Let us see how such analyses and interpretations can be simply converted into clear avenues for action.

FIG. 1
DISTRIBUTION OF SCRAP CHARGING TIME

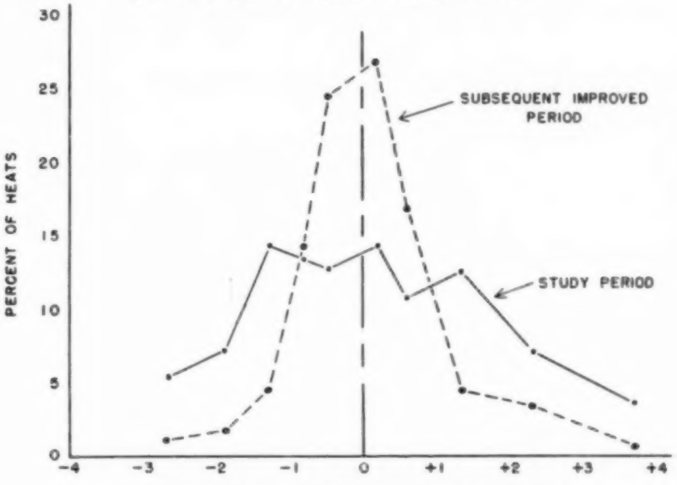


Figure 1 shows one of the simple forms of analysis known as the Frequency Distribution; it shows HOW OFTEN something happened and the MAGNITUDE of that occurrence. In this instance, scrap charging times for all furnaces in a given shop in a specific month were grouped in convenient intervals of time. The percentage of the total heats falling in each class interval was calculated and plotted. In this illustration, the intervals are shown as above and below the average time for the month, but could just as readily have been shown as the actual time in minutes. The solid line shows the arrangement of times which existed in the first, or study period. It will be noted that the curve was wide-spread and flat, had no pronounced peak, and indicated a tremendous variation in scrap charging times. This type of curve is known by analysts to be most unsatisfactory and abnormal.

This scrap charging phase of operations was then vigorously attacked. A subsequent period of one month was similarly calculated and plotted; this is the broken line on Figure 1. It so happens that the AVERAGE scrap charging time was IDENTICAL in the two periods, yet surely everyone will agree that performance in the subsequent month is to be preferred over that in the study period. The cases at the extreme ends, both very short and very long scrap charging times, have been considerably reduced; there is now a pronounced peak to the curve indicating greater consistency and uniformity of operations. Improvement HAS BEEN MADE, yet an examination of merely the AVERAGE of the times in the subsequent period would indicate efforts toward improvement had been to no avail.

Practically any of the day-to-day data resulting from open hearth operations can be so treated and converted into a picture of this type. It is a simple operation, not complicated or time consuming, and can be readily performed by any clerk. "But," it will be said, "that is still only history; it tells what HAS happened and not what IS HAPPENING." This is true, but an equally simple technique known as the Control Chart to be discussed below will present a picture of the day-to-day progress.

FIG. 2

DISTRIBUTION OF HEAT SIZES FOR ONE MONTH

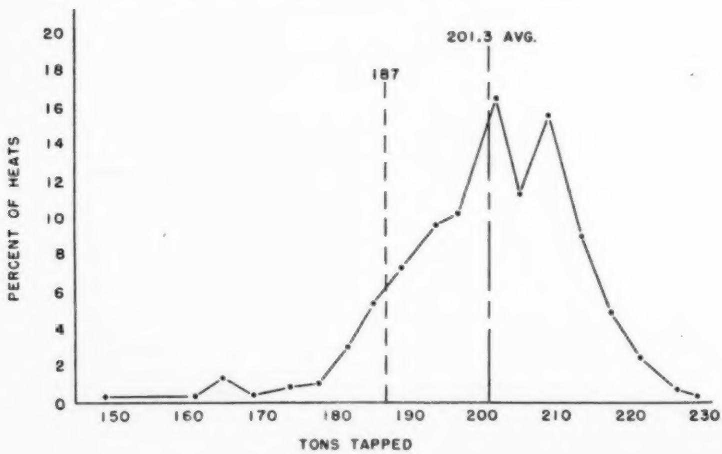
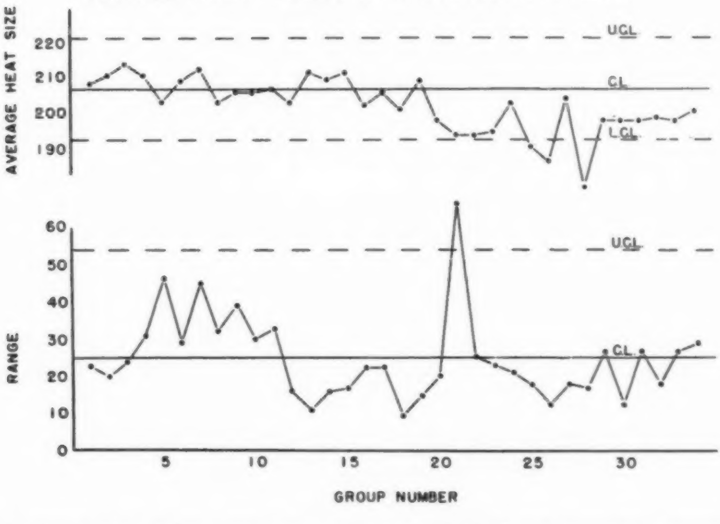


Figure 2. shows a frequency distribution of the sizes of heats tapped from furnaces of identical size and making the same grades of steel, for a period of one month. The AVERAGE heat size (201.3 tons) might be "considered" satisfactory as based on past history, but a quick look at the curve tells quite a different story. The spread is from 150 to 230 tons; the curve slopes steeply down in the high tonnage range where there are practical limitations to heat size; but it tails off gradually into the low tonnage range. This latter is a reflection of the attitude that "an occasional small heat is to be expected and doesn't hurt much." How frequently these "occasional small heats" are occurring and "how small" a heat should be expected to be is the crux of this problem.

In this case there were 41 heats below 187 tons in size, a figure which the correct analysis of these data indicates to be the smallest heat which should normally be expected, and if these 41 heats had been of only AVERAGE size the shop would have produced 900 tons of additional steel during the month.

This improved condition could not have been achieved merely by efforts to increase the AVERAGE heat size. Heats which are too large are more undesirable than heats which are too small. The emphasis must be on CONTROLLING VARIATION in heat size, and in attaining this the aim should be to eliminate the small heats and work toward the highest possible percentage of "standard" size heats. It is important that supervision have some criterion to judge what is "too small" or "too large" in order to have a picture of progress and it is here that the value of the Control Chart is evidenced.

FIG. 3
CONTROL CHART — SIZES OF 5 CONSECUTIVE HEATS



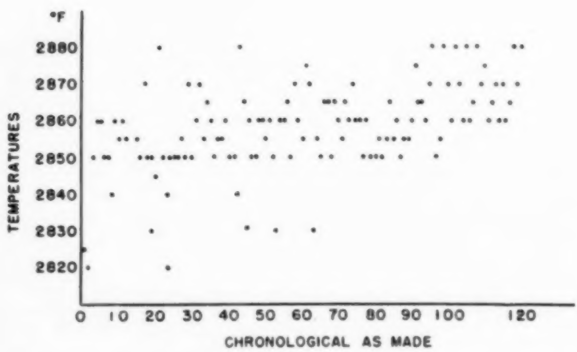
The same data have been arranged in Control Chart form in Figure 3. The upper portion of this chart shows the average size of five consecutive heats as each point, continuing chronologically from day to day. The lower portion shows the Range, or variation from largest to smallest within the corresponding group of five heats. The center lines (solid)

represent AVERAGE conditions from the previous period (judged satisfactory) and the broken lines are upper and lower "expectancy" limits. As long as conditions continue to run along as they formerly did, no average of five heats should be expected to go either above the upper line nor below the lower line for averages, nor should an individual range point be expected to fall above the range limit. If this does occur, or if a concentration of points appears close to these limit lines, SOMETHING HAS CHANGED and conditions should be investigated at once.

Examination of Figure 3 will show that things went along about as expected until the 21st group. Here the range suddenly went "out of control" indicating greatly increased variation in size from one heat to the next. Note, also, the concentration of "averages" near the lower limit line and that they finally went "out of control" on the low side. These low points are the cause for the long tail on the low side of the frequency distribution in Figure 2. If the control chart had been maintained daily during the production, and if supervision had taken action when action was indicated, (about the 20th group), these abnormally small heats could have been eliminated and the average heat size for the month increased 2.8 tons. Thus, the importance of VARIABILITY rather than AVERAGE as a determining factor in results, is clearly shown.

This control chart is likewise simple to construct, requires no specialized training and can be performed by anyone with a knowledge of eighth grade arithmetic. It is really a refinement of the familiar and over-used "running record" chart. In this latter type of chart INDIVIDUAL readings are plotted rather than AVERAGES and RANGES of small sub-groups as is done in the control chart. As a result, much important information is too frequently hidden.

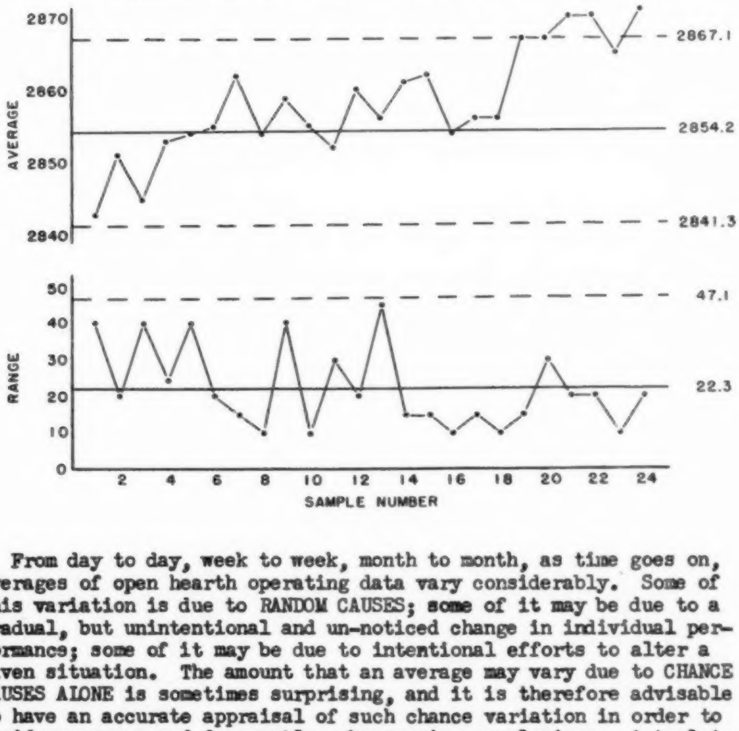
FIG. 4
POURING TEMPERATURES — INDIVIDUAL HEATS



A specific grade of steel, produced in rather considerable tonnages in a given shop, developed surface troubles in the billet stage. All the "well-known" causes were examined with no apparent success while the poor surface was becoming worse. Figure 4 shows the characteristic running record chart on pouring temperature, a factor of recognized importance. Very little worth-while information can be, or indeed was,

deduced from this chart. This same set of data, however, when treated in control chart manner as in Figure 5, and compared to prior history when the surface was relatively good, (the average and expectancy lines) immediately brought out the facts. The variation in pouring temperature from heat to heat masked the slowly increasing trend, and had the control chart method of analysis been in effect action could have been taken in time to PREVENT the bad surface which resulted when the pouring temperature finally exceeded tolerable levels. Just incidentally, a downward modification of pouring temperatures actually cleaned up the trouble.

FIG. 5
POURING TEMPERATURES — GROUPS OF 5 HEATS



From day to day, week to week, month to month, as time goes on, averages of open hearth operating data vary considerably. Some of this variation is due to RANDOM CAUSES; some of it may be due to a gradual, but unintentional and un-noticed change in individual performance; some of it may be due to intentional efforts to alter a given situation. The amount that an average may vary due to CHANCE CAUSES ALONE is sometimes surprising, and it is therefore advisable to have an accurate appraisal of such chance variation in order to avoid erroneous and frequently embarrassing conclusions. A tool to evaluate these changing conditions is available and is called Significance of Differences. It provides the means for indicating just what part chance has played in the changing level and with what degree of confidence the difference can be attributed to specific causes. These tests are quite adaptable to a large variety of situations, but require a little specialized training to execute, being somewhat more complicated than the frequency distribution or control chart techniques.

Table 1

SIGNIFICANCE OF DIFFERENCE BETWEEN PERIODS

SCRAP CHARGING TIMES

PERIOD	OBSERVED DIFFERENCE ABOVE OR BELOW 1ST PERIOD	ONLY-TO-BE-EXPECTED DIFFERENCE	ODDS THAT DIFFERENCE DUE TO CHANCE ONLY
1	——	——	——
2	−17 MINUTES	13.2 MINUTES	1 IN 5
3	+8 MINUTES	12.6 MINUTES	2 IN 3
4	−47 MINUTES	12.7 MINUTES	$<$1 IN 100

Table No. 1 is a tabulation of the analysis of scrap charging times in four weekly periods. In the first, or study period, a frequency distribution of times was made which indicated the average was high and the variability great. A campaign was instituted to "reduce scrap charging time" and the average for the second week was 17 minutes lower. Everyone was satisfied that their efforts had been rewarded, though the improvement was small, and the campaign was extended. In the third week the gain of 17 minutes in the second week was lost, plus an additional 8 minutes, for a total loss in the third week over the first of 25 minutes. How could this be?

Analysis of the data by difference techniques showed that if, in the second week, scrap had continued to be charged identically as in the first week, a difference of 13.2 minutes in the average, either up or down, could be expected merely due to chance variations in individual heat charging times. Further, it is a 1 in 5 chance that the observed difference of 17 minutes improvement was due to random variation. Since, in order to be significant, this chance would have to be at least 1 in 20, it was decided that the method of attack in the second week had possibly resulted in no real improvement. This was borne out when similar methods used during the third week resulted in an even higher figure than in the first week. Analysis here shows that a difference, up or down, of 12.6 minutes in charging time could have been expected due to purely random chance causes and, further, that it is a 2 in 3 chance that the change in average WAS merely fortuitous.

Accordingly, a new method of attack was selected for the fourth week and an improvement over the study period of 47 minutes in the average

resulted. Calculation now shows that the chances are 99 in 100 that the improvement was NOT due to chance but to the action taken. A further test was applied and frequency distribution of times in the fourth week plotted. Although the average time was reduced, the significant change was in VARIATION of scrap charging times from heat to heat. The next logical step would be to set up a control chart to show the day to day progress and level so that immediate action may be taken to keep things "in the groove." No doubt supervision did have something to do with the improved figure in the second week, but the variability of the system was so great that no permanent improvement could be attained until this was substantially reduced.

Another very common problem in analyzing open hearth data is the study of relationships. Operators are constantly faced with determining the relationship between fuel rate and furnace life, per cent of hot metal in the charge and tons per hour; per cent of limestone charged and heat time or final sulphur, and a hundred or a thousand other such relationships. The conventional method has been to plot values representing the characteristics to be studied on graph paper and draw, by inspection, the line which seems to represent the best relationship. A more advanced method is to determine these lines by mathematical calculation, a technique known as correlation. Sometimes these are straight lines, sometimes curved.

It is a well recognized, but not sufficiently well appreciated or understood, fact that the study of such a simple relationship is, in reality, not simple at all. There are many other variables affecting final sulphur other than the limestone charged; many things may, and probably do, have a much more pronounced effect on furnace life than fuel rate. For this reason it is all too frequently quite misleading to draw conclusions from the apparent relationship existing between fuel rate and furnace life, and ignore all the other variables that are known to exert a pronounced effect and which were undoubtedly exerting their respective effects to varying degrees concurrent with the variations of fuel rate, the item under study.

Is there a way by which we can include the varying effects of several of these variables, or perhaps all of the recognized ones, and then sort out the individual and independent effect of each one by itself, excluding the effects of all the others? Yes, there is such a tool and it is known as Multiple Correlation. As a simple example, if we should study the relationship existing between Tons per Hour and (1) scrap charging time, (2) pounds of limestone charged, (3) per cent of hot metal charged, (4) sulphur in the hot metal, and (5) fuel rate, the results obtained by this multiple correlation analysis would show the specific effect of any one of the 5 variables on tons per hour independent of the effect of any of the other four.

This is quite an involved and complicated technique, impossible of execution without some highly specialized training. Until recently it was also extremely laborious, but certain technological advances in methods and equipment have shortened it materially. There are two definite phases involved; first, the mathematical computation and, second, the useful interpretation. The first has been available for years but the second has been noticeably lacking. Obviously, any mathematical result must be interpreted so that it can be intelligently used by operators. The mathematician has a woeful lack of practical open hearth operating experience, and the mathematical procedures have not been readily available to the operators.

Let us examine the potentialities of this tool to assist in solving a problem of universal interest to all open hearth operators, and one which practically defies solution except by the use of this specialized technique.

Fig. 6

ROUGH DIVISION OF TOTAL HEAT TIME

A	B	C	D

A.	CHARGE SCRAP	START CHARGE TO FINISH CHARGE SCRAP
B.	CHARGE HOT METAL	FINISH CHARGE SCRAP TO FINISH CHARGE HOT METAL
C.	WORKING	FINISH CHARGE HOT METAL TO TAP
D.	IDLE	TAP TO START CHARGE

Everyone is interested in reducing total heat time. The correct approach to this is a study of the VARIABILITY of heat times. If we knew what combination of events resulted in short heat times, what caused long heat times, and if we could eliminate or materially reduce the number of long ones, life in an open hearth shop would be a much happier one. Suppose we examine this variability situation a little.

Figure 6 shows one rather common and logical way of dividing up the total heat time, charge to charge. Variations in Period A will depend on many factors, such as furnace size; amount of scrap charged; physical nature of scrap; charging box size; type of fuel and rate of firing; transportation and other charging facilities; number of furnaces charging at one time, etc., etc. Period B will vary according to the amount of hot metal being charged and availability of same; ladle size; condition of furnace and charge at time of adding, etc., etc. It would take a long time to enumerate the known, or suspected causes of variation in Period C and similarly for Period D. Every operator has his own ideas about these various factors; there is reasonable agreement on some but violent disagreement on others. What are the FACTS? Again, the correct approach is a study of the various factors responsible for variations in elapsed time of these individual periods, or similar periods, and the relationships existing between those factors affecting an individual period, as well as the relationships between the periods themselves and the effects of these relationships on total heat time.

TABLE 2
RELATIVE IMPORTANCE OF FOUR PERIODS IN TOTAL HEAT TIME

EFFECT ON VARIATION	FURNACE NUMBER 1	2	3	4	5	6	7
MOST IMPORTANT	C	D	A	A	B	A	C
NEXT MOST IMPORTANT	A	A	C	C	A	B	B
THIRD MOST IMPORTANT	B	C	B	D	C	D	A
LEAST IMPORTANT	D	B	D	B	D	C	D

Data were collected for a period of time, by individual furnace, and analyzed. A study of the relationship of the periods A, B, C and D to total heat time was made to determine the ranking order of importance that their respective variations had on the variation in total heat time. This data is tabulated in Table No. 2. It will be observed that the same period is not of primary importance on all furnaces and that a specific period changes its position of importance from one furnace to another.

A "Conventional" analysis was made on one furnace, showing merely the apparent relationship between each period, separately, and the total. This indicated the scrap charging period to be the major offender, yet when analyzed by the multiple correlation method the effects of various combinations which existed were eliminated, and it was found that actually the idle period was greatest in importance.

FIG. 7
FURTHER REFINEMENT IN DIVISION OF TOTAL HEAT TIME

B-1 FINISH CHARGE SCRAP TO START ADD HOT METAL

B-2 START ADD HOT METAL TO FINISH ADD HOT METAL

C-1 FINISH ADD HOT METAL TO START LIME BOIL

C-2 START LIME BOIL TO FINISH LIME BOIL

C-3 FINISH LIME BOIL TO TAP

A little study of operating conditions along the foregoing lines will quickly develop some interesting, and perhaps hitherto unsuspected facts. A probable logical conclusion will be that some further refinement in division of total heat time is indicated. For example, as in Figure 7, the original Period B might be divided into B-1 and B-2; Period C might be further sub-divided into C-1, C-2, and C-3, etc. As things become more and more complicated the absolute necessity for some mathematical process to keep our thinking straight becomes apparent.

The result of such studies will, undoubtedly, evolve optimum working ranges for the various periods. It may develop, for example, that it is undersirable to reduce a specific period to too low a point because of the adverse effect this would have on some following period, thus resulting in an overall increase in heat time, a net loss. This is a virtually untouched field and offers promise of very lucrative returns.

To sum up, there are numerous modern statistical tools available to open hearth operators to aid them in a more rapid and factual evaluation of operating data. Some of these are extremely simple and easy of execution; others are moderately involved, and some are highly technical and laborious. Immediate use could be made of the simple ones by any open hearth operator. These would lead to an appreciation of the somewhat technical ones and a realization of their value to progress. The universal results, if properly handled, will be the substitution of fact for opinion, the establishment of definite bench marks, an improved and sharper knowledge of what a process or part thereof can be expected to do, the high-lighting of the most important factors, and the spot-lighting of the trouble spots, thus enabling supervision to make the best possible use of their time and effort, the cracking of the tough problems and, finally, and most important of all, an easier and happier lot for melt shop supervision.

QUALITY CONTROL AT WORK IN THE STEEL FOUNDRY

Harold H. Johnson
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When the word "foundry" is mentioned, the picture that may come to the mind of most people is that of a ramshackle, disorderly sort of a place, full of sand and dust and fumes, weirdly illuminated by the glow of molten metal through the haze of smoke, and presided over by an unshaven individual, with a big cud of tobacco in his cheek. Along with this picture goes also the conception that, in general, castings are chunks of metal that are approximately the size and shape required for the purpose for which they are intended and that their quality may be good, bad, or indifferent.

While this may have been true many years ago, and still may be true in some instances, the industry as a whole has developed during the last 30 years until now the production of castings is on a quite controlled basis. The foundry has become mechanized and air conditioned, the processes involved have been standardized and controlled, and the resulting product is made to tolerances that permit the casting to be readily adapted to the next step in its machining or in its application. Quality levels of the materials in the castings have been raised and standardized until the consumer is assured of securing a product that will consistently meet his requirements. One of the tools which the foundry industry is finding useful in meeting and maintaining these quality standards is that of Statistical Quality Control and it is the purpose of this discourse to indicate how this technique is being applied.

Now the term "foundry" covers a wide variety of units. Some foundries produce malleable iron castings, others grey iron, steel, brass, or aluminum castings. Some foundries are large, mechanized, high production units while others are small jobbing shops. Most of the casting production is used in the automotive, agricultural machinery, and railroad industries, although there are a multitude of other uses for castings. Castings may weigh only a few ounces or they may weigh several tons. The production may range from a variety of small castings supplied to diversified industries (such as are pictured in figure 1) to that of large machinery castings weighing many tons (of which figure 2 may be a representative picture). The shop with which the writer is connected produces "medium size" steel castings, principally for the railroads. Typical of such production is a freight car side frame, weighing about 700# (figure 3).

Fig. I.
Miscellaneous Small Castings

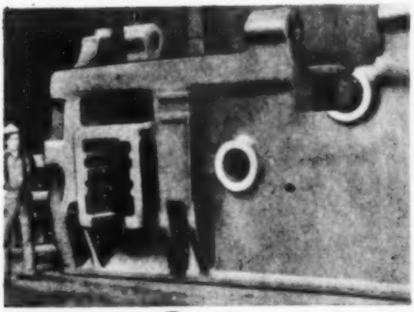

Fig. 2.
Large Machinery Castings

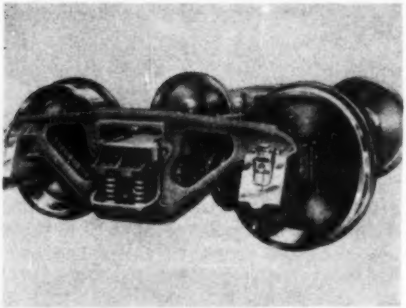

Fig. 3
Side Frame for Freight Car

As would be expected, quality control methods find their most profitable application in the high production foundries where certain castings are produced over a long continuous run although the control techniques can be profitably applied in many smaller foundries. Because the writer is connected with a mechanized foundry producing steel castings,many of the applications discussed will be as applied to this type of production. Quality Control has shown itself to be a very useful tool in many foundries, both for the control of variables in the process as well as for evaluating the quality of the finished castings.

In very general terms, a casting is made by making an impression of the casting in sand (using a pattern of the casting for this purpose) and then filling the mold with molten metal of the desired analysis. When the metal has solidified, the sand can be removed and the casting is left. The principal "raw" materials that are needed then, are sand and molten metal.

The sand used must be moldable and yet able to stand up under the attack of the molten metal and, therefore, is carefully selected as to grain size distribution and characteristics, but before it can be molded it must be bonded with materials such as bentonite and water to meet certain physical requirements. In order to obtain a thorough mixing of the sand with these bonding materials, they are mixed together in a unit called a muller. Figure 4 is a photograph of the hopper and weighing mechanism for weighing the sand that goes into such a batch, and of the sand mill itself.

Fig. 4
Sand Mill

As a measure of the physical properties of such sand mixes a sample is taken from almost every mill, which is tested for strength (green bond), for moisture content, and for resistance to the flow of gases through it (permeability). The results of such tests can be shown on $\bar{X}$, R charts in two ways. One set of charts can be made as the results of individual tests are entered for the purpose of obtaining control information as to the variation and level from mill to mill. The other set of $\bar{X}$, R charts is made up using the average value from each turn's tests as the individual points. This type of chart gives a "long-range" picture which is useful in making adjustments in practice over a period of time. Thus, a given system sand may become finer or coarser as more or less of the fine, inert materials are left after passing through the reclamation system, or even as the character of the incoming new sand may slowly change over a period of weeks or months. Such changes may be gradual, and may not be noted except as a trend is established. Figure 5 shows an $\bar{X}$, R chart for the Moisture control from mill to mill, while figure 6 shows the changes in Permeability over a period of time. It will be observed from Figure 5, that we are operating within fixed limits for this property, which limits were based on satisfactory results obtained over a considerable period of operation. This makes for simplicity in charting and at the same time, assures us of a satisfactory moisture control. Groups of 4 or 5 individual determinations are used in all our charting. In Figure 6 we note the level and spread of permeability obtained when each of three types of sand were used. Such a chart is especially valuable for noting trends over a period of operation.

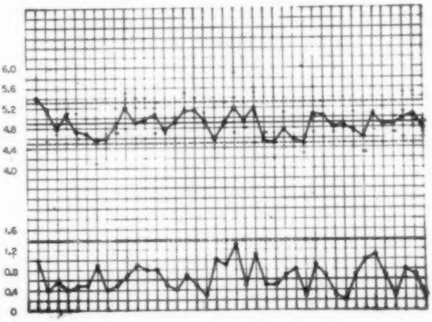

Fig. 5
Moisture Determinations, Mill to mill.

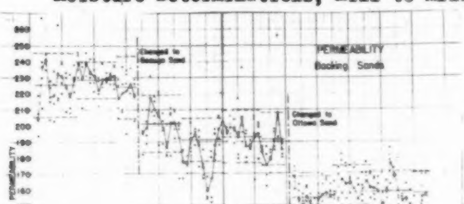

Fig. 6
Permeability Determinations

While most of the sand is molded in this "green" condition, some sand is bonded so that it can be baked into cores. These cores are used to "hollow out" castings and to form desired contours inside of them. The physical requirements for such sand, while quite different from those of the sand which is to be used in the green state, are controlled and charted as carefully as those of the green sand. When the cores are baked, they are quite hard so that they can be readily handled both for transportation to the mold and so that they can be set in place in the molds. Figure 7 shows a very large core being set in place in a mold.

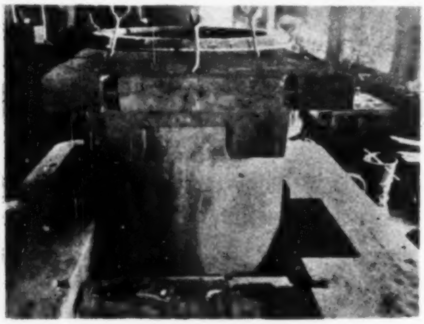

Fig. 7
Core Being Set In Mold

The dimensional control of these cores and their spacing in the mold is a very obvious field for quality control. Many of the cores are only visually inspected, while others are gauged, using a go, no-go gauge such as is shown in Figure 8. Some are set in a jig and passed under a grinding wheel which assures that they will be the right thickness. The setting or spacing in the mold of the cores is another step which requires gauging to assure the proper setting.

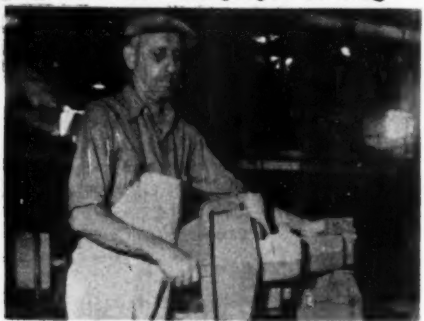

Fig. 8
Gauging a Core

Most foundries do not measure the absolute dimensions of the cores other than as described, but some core dimensions are of such importance that they are actually measured. The cores to be measured are selected on the basis of an approved sampling plan and, thus, are representative of the production from which they were selected. In general, $\overline{X}$, R charts are used to display the measurements and the action to be taken is indicated by such charts.

A further step in this control is found by measuring critical dimen-

sions on the castings themselves and referring these back to the corresponding core "dimensions". Thus, in the production of couplers for railroad freight cars, there is a critical dimension between the lugs. Couplers are selected by a sampling plan and this dimension, which is determined by the core width, is measured and charted as shown in Figure 9.

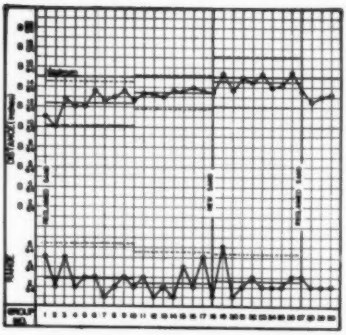

Fig. 9
Distance Between Pivot Lugs, E61 Coupler

For functional purposes, this dimension has a maximum tolerance of 8-15/32" set on it and the Upper Control Limit for the first eighteen groups as tabulated does not exceed this value. At the time of the eighteenth group, a change was made in the core sand mixture in an attempt to minimize some other difficulties and, to our surprise, this change was reflected in the casting dimension that is determined by this core. In other words, the changed sand mixture did not bond itself together as tightly as the previous mixture had done and we have an increase in core size which is reflected in the casting dimension. The first steps taken to correct this condition was the return to the reclaimed sand mix and this change was reflected in the return to the width level of the first eighteen groups. Here we have a good example of the use of such charting to serve as a measure of the effects of a process change.

Numerous other examples could be given to show the application of control charts to evaluating measured controls in the molding practice. Such measurements might include the uniformity of ramming of the molds, the hardness of cores, the analysis of defective cores and of defective molds, (by means of p-charts), even the measurements of core uniformity by measuring and charting the density of certain baked cores. Numerous other applications could be cited, but are omitted in the interests of brevity.

We must also consider some of the controls involved in the melting operation which produces the molten metal with which to fill these molds. The type of furnace depends on the kind of metal being melted and the amount being produced. Thus, the cupola is commonly used for grey iron and a cupola-air furnace combination for malleable iron, while for steel the open hearth or the electric furnaces are most frequently used. The photograph of Figure 10 is that of an electric furnace tapping nine tons of molten steel into the receiving ladle, from which the molds are poured.

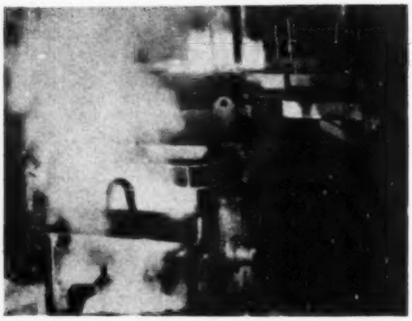

Fig. 10
Electric Furnace

The melting process, no matter what the type of melting unit used, is fundamentally the same. It consists in charging scrap of various and sundry sizes and shapes (but usually of an analysis suited to the process) into a furnace where enough heat is applied to melt the scrap and to heat the molten bath to the required temperature for pouring. Chemical reactions go on in the bath at these elevated temperatures as surely as they go on in an experiment in the laboratory and it is the function of the melter to cause and to control these reactions in order to produce the metal of the desired quality. Means have, therefore, been established for measuring fluctuations in some of the steps of the melting processes so that corrective measures can be taken to maintain the desired quality and statistical methods have become of value in helping to evaluate and to control these measured steps.

For example, chemical analyses are made on every heat of steel in our shop (and in most shops) in order to be sure that the material meets certain specifications. In addition, it is recognized that for each grade of steel the analyses for carbon and manganese should fall within certain limits in order that when the castings are given a specified heat treatment they will have certain physical properties.

In our shop (and I suspect in many other shops) we have been content to make analyses, to look them over, and as long as they were apparently within certain limits to file the analysis sheets away and to forget them.

One day we got the idea that here was something that would be a "natural" for control study because we have measurements that have been accurately and systematically made and whose control (or lack of it) affected the processing quite considerably. $\bar{X}$, R charts for carbon and manganese were established for each grade of steel and limits recalculated for each group of 40 heats until we had a background of analyses from several hundred heats charted.

We noted that both the average values and the control limits were exhibiting considerable uniformity for each grade of steel and that the process was operating at a satisfactory level under these conditions so that we established our charts with fixed limits, as shown in Figure 11.

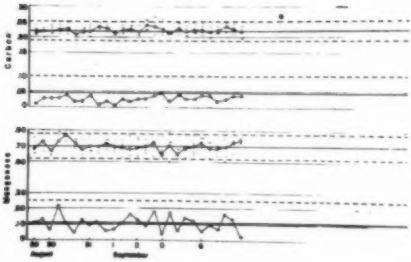

Fig. 11
Carbon and Manganese Control

We continue to plot the carbon and manganese values as soon as they become available (and we also include silicon values for certain grades of steel) and as long as the average and range points stay within the fixed limits (or no more than 1 in 100 falls outside these limits) we are satisfied with the process control. However, as soon as we detect a trend in either direction from the average, or the scatter of results becomes great enough to cause points to go out of control limits, action is called for. Whenever any changes are made in the process which will call for a change in the location of these limits, we then resume recalculation of the limits after each 40 determinations until we have a sufficient background to establish new fixed limits.

A second step which we have with these chemistry charts is to break down the data so that the plotting is by melters or even by first helpers on the furnaces. The purpose of this step is two-fold; (1) to create some competition among the operators to produce the desired results, and (2) to better be able to determine which operators are producing unsatisfactory results so that their technique can be corrected. Such charts then form a factual, impersonal basis for discussion between men and supervisors or even between the men themselves. When the results are unsatisfactory, the charts furnish a starting point for correcting the difficulties, and when improvements have been made they provide the incentive for a "pat on the back".

The results have been very satisfactory from our viewpoint because they have enabled us to secure better chemical control than we had ever thought possible and this, in turn, has resulted in a more uniform product and indirectly in a lower level of rejections.

At other steps in the melting process, analyses are made of the metal or of the slag and these analyses furnish the material for other charts that are quite useful.

Among other variables which have been measured and charted are those of power consumption, time from tapping of one heat to tapping of the next one from each furnace, temperature measurements (by operators, by types of steel, etc.) and fluidity measurements.

As an example in Figure 12, we have superimposed on one chart sections from three charts which show the differences between these three

operators as measured by the elapsed time of their heats from tap to tap. The operators are working side by side under very similar conditions, but the differences in their ability, industry, and their individual methods of making heats is somewhat reflected in these measurements. As the charts of the individual operators are plotted over an extended period of time, changes and trends in their performance maybe readily and accurately noted and corrective steps taken.

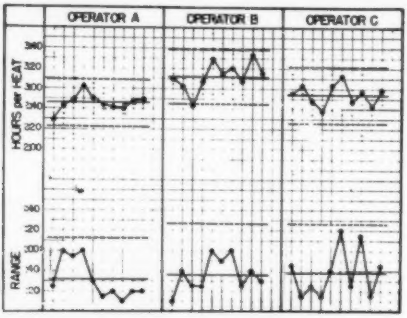

Fig. 12
Time of Heats by Melters

Correlation charts of the type shown in Figure 13 have proven to be of some value under certain conditions. Here we have two measurements for essentially the same property of the metal. The "film" test measures the temperature while the "fluidity" test integrates the temperature and fluidity factors. If both measurements are carefully made, there should be an excellent degree of correlation such as for operator A, but if the measurements are poorly made, the degree of correlation will be poor as for operator B. Again we have a factual, clear cut basis for discussion and a measure of any improvement that may be made.

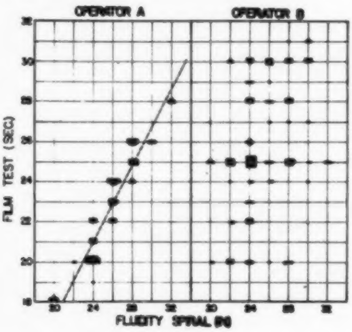

Fig. 13
Correlation Chart for Temperature-Fluidity Measurements.

When the metal has been poured into the molds, they are allowed to stand (or to ride on the pouring conveyor) until the metal has solidified, and then the castings are "shaken out" or removed from the sand.

The sand is returned to a reclamation system to be reconditioned for further use. The castings are conveyed or transported to the "rough trim" when gates and feeders are removed as well as adhering cores, core rods, etc. If the foundry is producing small castings in a continuous process, samples of these rough, uncleaned castings are selected (on a sampling plan) as they move along the conveyor to the "rough trim". The samples are checked for defects and p-charts are plotted for each of the important types of castings for the major classes of defects. In this way, unsatisfactory castings may be spotted immediately after they are made and the nature and degree of defectives evaluated so that action can be taken.

Where larger castings are involved, their number will be less so that usually they are inspected 100% in the "green" state and defects charted, using the p-chart technique.

They are then "rough chipped" and heat treated to change the coarse grained, brittle, as cast structure into a fine grained, ductile, machinable structure. Heat treatment varies widely for different types of castings but the purpose is all the same.

Following heat treatment, the castings are cleaned to remove adhering scale and sand and they are then chipped and ground to condition the castings both as to the desired appearance and to meet the required gages. As for the cores, most of the gages are of the go, no-go type because these are adequate for most tolerance requirements. Figure 14 shows an inspector applying such gages to couplers that are to be applied to freight cars.

Fig. 14
Inspector Applying Gauges to Couplers

We have found that there are certain "critical" dimensions which must be held within the prescribed tolerances and we have, therefore, set up a practice of selecting samples from each day's production on which these dimensions are measured and the results charted using the $\overline{X}$, R type of chart. The chart referred to in figure 8 is typical of this type of measurement and control. By the use of this technique, better conditions for fitting and conditioning are maintained with attendant economics in production and with greater customer satisfaction. This whole scheme of dimensional control, of course, is but an adaptation from well-known machine shop practice applications which have pro-

ven so very valuable.

Similarly, the mechanical properties of the several grades of steel are charted, using the $\bar{X}$, R type of charting, and these charts are used as a control guide for maintaining the required quality level. One criterion for evaluating this level is to determine periodically the percent of heats that may be expected to fail, on the first test, to meet the minimum requirements. That amount can be estimated by applying the technique of Algebraic Probability and the Normal Curve of Error and figures so obtained form a tangible and accurate basis for comparison and evaluation of these properties.

Beyond dimensional checking of castings, the most commonly used test for measuring their quality is to look them over for obvious defects. Of course, such inspection is not confined to looking at the castings just before they are shipped, but in most shops they are inspected as they are progressing through the several steps in the operation.

One Malleable shop reports, for example, that they have placed p-charts for scrap on each grinder in the cleaning room and that inspectors check every machine every hour to see that the castings are being properly ground and to record the scrap. Each inspector is also responsible for checking each load before it leaves the department. P-charts are also placed on drill presses, tapping machines, and punch presses and checks are made on an hourly basis. After a load has been inspected, the inspector places a small tag, which he has signed, on it to signify that the load may be moved.

It is always desirable to correlate the nature of the defects and the number of defective castings with the production period. A tabulation can be made of such castings, such as is shown in figure 15, where the items can be identified by a serial number or by a heat number. The results can then be plotted in the form of a histogram, such as is shown in figure 16, or in the form of a p-chart for each major type of defect. Any such scheme is of great value in analyzing the nature and occurence of defective castings and in indicating where corrective measures should be taken.

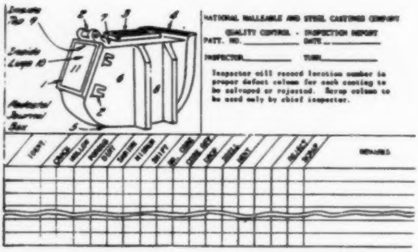

Fig. 15
Inspector's Report Sheet

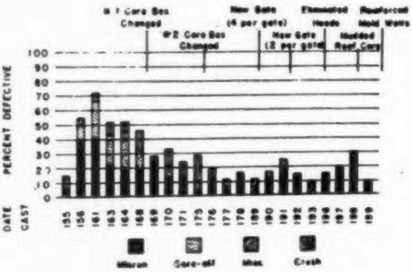

Fig. 16
Histogram for Defects

One other statistical technique which has been found useful to a limited extent, is that of "moving averages" . An application of this technique was found when we became interested in noting and recording the type of fracture exhibited when a tensile test bar was pulled.

It is well known that such fractures could be trouped into two general classes, designated as "cupped" and "non-cupped". Further, it is generally agreed that the type of fracture is related to the quality of the steel and, that an unflawed bar breaking with a "non-cupped" fracture probably represents steel of poorer quality than a bar that breaks with a cupped fracture. This then becomes another measurement of the quality of the steel which is noted from the tensile test results.

We found that if we charted the percent of non-cupped fractures using the "moving average" technique, taking groups of 50 test results at a time and dropping ten and adding ten for each point, that cycles soon became apparent as shown in figure 17.

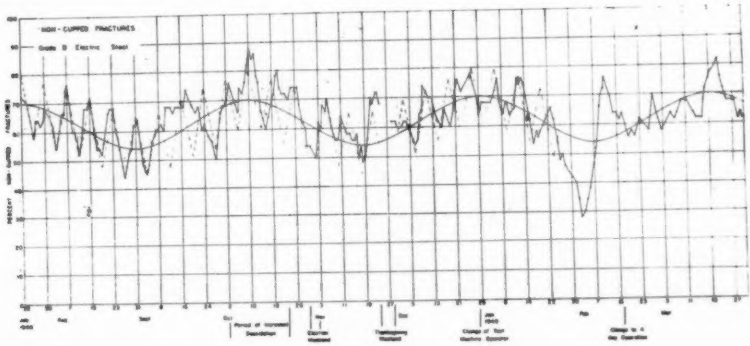

Fig. 17
Moving Average Chart for Fractures of Test Bars

Starting out, we see how these points fluctuate in an eight calendar day cycle and how this regular fluctuation continues for several periods. Then apparently some process change was made so that the eight day cycle was only approximated and finally was lost. However, over a considerable period of time, an eighty day cycle appeared and continued over a considerable period of time. This cycle was finally broken by some process and chemistry changes.

We have been trying to show in this discussion how Statistical Quality Control methods have been applied to both the process control in the foundry as well as to controlling the quality of the castings themselves. This represents a comparatively new field for the application of such methods and it apparently will be a very fruitful one.

THE INTERPRETATION OF CHEMICAL DATA

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Introduction

The usefulness of statistical methods for the interpretation of chemical data is, in general, best illustrated by selecting a particular chemical problem and showing in some detail the appropriate statistical operations on the data. Reliance is then placed on the hope that chemists will recognize similar chemical situations and apply the same statistical technique. Unfortunately the numerical procedures are sometimes literally copied without a clear understanding of the statistical ideas involved. Statistical formulas are usually put in a form to facilitate the arithmetical operations, and this often conceals the thoughts underlying these formulas. The numerical operations in this paper are intended to reveal the ideas behind one statistical technique which has wide areas of application. It is reasonable to expect that more chemists will use statistical techniques and with greater confidence in the statistical verdicts if the logic of the statistical procedure is understood.

Measures of Variation

There are numerous ways of expressing the fact that repeated measurements of the same quantity do not yield exactly the same result. It is common practice, if just two measurements are available, to state the difference between the duplicate measurements. When larger sets of data are examined the arithmetical average of the set is first found and then the absolute difference taken between each measurement and the average. The average value of these differences is found and this is called the average deviation. This is a popular procedure among chemists. The average deviation is subject to certain awkward limitations and the statistician prefers to square the differences, sum these squares, divide by one less than the number of measurements and extract the square root. The result is called the standard deviation. This measure is more work to compute but the advantages are worth the additional labor of computation. A simple numerical example is given in Table I.

Table I

Measures of Variation

	Data	Absolute Difference	Square of Difference
	1.04	.01	.0001
	1.08	.03	.0009
	1.03	.02	.0004
	1.06	.01	.0001
	1.04	.01	.0001
Sum	5.25	.08	.0016
Av.	1.05		

$$\text{Average deviation} = \frac{0.08}{5} = 0.016$$

$$\text{Standard deviation} = \sqrt{\frac{0.0016}{4}} = 0.020$$

The existence of several methods of measuring variation should occasion no surprise to chemists who have devised a whole list of methods of expressing the concentration of a substance in solution. The concentration may be expressed as per cent by weight or volume, or molar concentration, or pH, or other unit. It is proper to expect the statistician to show the chemist why the standard deviation is the desirable unit to express variation. The chemist will be more inclined to use this unit if he is convinced that by its use he can make a more searching examination of his data.

Why Statisticians Use the Standard Deviation

Given a set of repeated measurements of the same quantity they will usually cluster more or less symmetrically about the arithmetic average of the set. The various units for measuring the variation among measurements all serve the purpose of providing a measure of how tightly the individual measurements cluster about the average. For large sets of data the standard deviation turns out to be approximately 1.25 times as large as the average deviation. Mathematicians have shown that if a very large set of data is arbitrarily split up into many sub-sets and the average deviation and standard deviation computed for every sub-set, then the various values for the standard deviation are in closer agreement among themselves than are the values for the average deviation. Consequently if only one sub-set is available the standard deviation may be expected to give a better estimate of the variation of the whole set than will be obtained using the average deviation.

An Important Property of the Standard Deviation

The variation exhibited by the individual measurements in a set of repeated measurements is concisely summarized by the standard deviation. If the individual measurements are now

grouped in pairs and the average found for each pair a familiar result is obtained. The pair averages display a smaller variation among themselves than the variation shown by the individual measurements. In fact the standard deviation for the pair averages may be closely predicted by dividing the standard deviation for the individual measurements by the $\sqrt{2}$. This is merely a particular case of the widely known general rule which states that the standard deviation of the average of n measurements is found by dividing the standard deviation of the individual measurements by the $\sqrt{n}$. It is this rule which will be used in the following discussion of a set of measurements. It will be used in the reverse order from the way the rule is stated, i.e., it will be used to estimate the standard deviation of individual measurements by multiplying by the $\sqrt{n}$ the standard deviation calculated from a set of averages, where each average is based upon n measurements.

Examination of a Set of Measurements

Suppose that 21 measurements of the same quantity are available. Such sets of measurements arise in a multitude of ways. They may be the per cent yield or per cent impurity in 21 batches in a production process. The study of an analytical procedure often leads to a fairly lengthy series of repeated measurements for the direct purpose of ascertaining the precision. Sometimes a sample of material is analysed by several laboratories each making two or three or more determinations. For the moment consider that the following measurements (Table II) are presumably all measurements of the same quantity. They are listed

Table II

Twenty-one Individual Measurements

								Av.
	8.99	9.09	8.76	8.93	9.29	8.48	8.77	8.901
	8.39	8.71	9.27	8.85	8.76	8.32	9.23	8.790
	8.34	8.78	8.18	8.88	8.87	8.86	9.02	8.704
Av.	8.57	8.86	8.74	8.89	8.97	8.55	9.01	8.799

in seven columns, each column with three entries. Defer for the moment, any inquiry regarding the basis for this grouping of the measurements. The average for each column is shown below the column and the average across each row is shown at the right.

The idea may occur to the chemist to compute the standard deviation for the seven column averages and to compute also the standard deviation for the three row averages. It would be expected that the row averages, being based upon seven measurements, would show less variation and therefore have a smaller standard deviation than the column averages which are based upon only three measurements. It seems logical to multiply the standard deviation computed

from the rows by the $\sqrt{7}$ and thus, by the rule, obtain an estimate of the standard deviation of the individual measurements. Similarly, multiplying the standard deviation found for the column averages by the $\sqrt{3}$ should be an alternative way of obtaining an estimate of the standard deviation of the individual measurements. There is only the one set of 21 measurements so that these two procedures should be expected to come out with approximately the same result for the standard deviation of the individual measurements. As a matter of curiosity suppose these numerical operations are performed leading to the following results.

	Standard Deviation	Multiply by	Estimated S.D. for Individual Measurements
Rows	0.09876	$\sqrt{7}$	0.2613
Cols.	0.18425	$\sqrt{3}$	0.3191

The next thing to make clear is that it would be extremely convenient to have at hand a means of comparing these two estimates of the standard deviation of the individual measurements. One important reason for wishing to compare these two estimates is that it is possible to conceive of a situation in which these two estimates could be expected to disagree. Suppose, for example, all three measurements in the first column are individually increased by 1.40. The result of this is to raise the average of the first column by 1.40 leaving the other column averages unaltered. Quite a different result is obtained for the row averages. Since all row totals will be raised by 1.40, all three averages will go up by 0.20. The standard deviation of the row averages is left unaltered by this constant addition to each row average. The standard deviation for the column averages is substantially increased by the increase of 1.40 in the average for the first column. The new estimate is $\sqrt{3} \times 0.4553$ or .7886 as compared with the previous value of 0.3191.

The following things should be apparent:

(a) that any constant increment to the measurements in a column does not affect the standard deviation for the rows.

(b) that one or more columns may undergo such constant additions or subtractions, the amounts being different for different columns without altering the standard deviation computed for the rows.

(c) that if it should be possible to appraise or detect a difference between the two estimates of the standard deviation for the individual measurements, this would provide a basis for deciding that some sort of difference existed between the columns. This would be important if, in arranging the data in the table, the columns corresponded to triplicate analyses reported by seven different laboratories, or to successive batches by seven different machines.

(d) that exactly the same arguments may be carried out by supposing some constant addition to all the entries in a given row.

So long as it is known that in the arrangement of the data the possibility of constant additions is restricted to either rows <u>or</u> columns the interpretation of a disparity between the two estimates for the standard deviation of individual measurements is quite simple. It is necessary to call upon statistical tables to provide a guide for passing judgment upon the two estimates of the standard deviation. If the columns are suspected of being subject to constant additions the following ratio is computed:

$$\frac{\text{square of the standard deviation as estimated from columns}}{\text{square of the standard deviation as estimated from rows}}$$

This ratio is called F. Note that it was not really necessary to go through the step of taking the square root since this ratio is in terms of the squares of the standard deviations. Tables provide critical ratios for F, for various numbers of rows and columns, which are rarely exceeded if there are no constant additions to the column entries. The F ratio for columns to rows before the addition of the constant to the first column was 0.1018/0.0683 or 1.490 and after the addition of the constant the F ratio became 0.6219/0.0683 or 9.105. The F ratio does not exceed 19.3, the five per cent critical value given in the F table.

Table III

Critical F Ratios - 5 Per cent Level

	Degrees of Freedom	For Numerator 1	2	3	4	5	6
	2	18.51	19.00	19.16	19.25	19.30	19.33
	4	7.71	6.94	6.59	6.39	6.26	6.16
	8	5.32	4.46	4.07	3.84	3.69	3.58
	9	5.12	4.26	3.86	3.63	3.48	3.37
For	12	4.75	3.88	3.49	3.26	3.11	3.00
Denominator	16	4.49	3.63	3.24	3.01	2.85	2.74
	20	4.35	3.49	3.10	2.87	2.71	2.60
	24	4.26	3.40	3.01	2.78	2.62	2.51

The Table is entered with Degrees of Freedom equal to one less than the number of rows and columns.

This Table is extracted from Fisher and Yates "Statistical Tables for Biological, Agricultural and Medical Research".

Chemists will not be slow to point out that both columns and rows may be subject to constant additions and therefore both numerator and denominator of the above ratio would increase and the ratio would fail as a measure of detecting experimental effects. Obviously what is needed is a third estimate of the standard deviation of the individual measurements which would be immune to the row and column additions. It is very easy to obtain this further

estimate and it is one normally used in the denominator of the F ratio. A separate F ratio is then computed for both rows and columns.

It will now be shown that there does exist a means of computing an estimate of the standard deviation of the individual measurements even if both rows and columns have undergone additions of constant quantities. For simplicity consider the special case where the number of rows is equal to the number of columns. Arrange nine measurements all of the same quantity in a square as follows

$$
\begin{array}{lccccc}
 & & & & & \text{Av.} \\
 & x_1 & x_2 & x_3 & & \bar{x} \\
 & x_1' & x_2' & x_3' & & \bar{x}' \\
 & x_1'' & x_2'' & x_3'' & & \bar{x}'' \\
\text{Av.} & \bar{x}_1 & \bar{x}_2 & \bar{x}_3 & &
\end{array}
$$

Now add a constant <u>a</u> to all entries in the first row and a constant <u>b</u> to all entries in, say, the second column

$$
\begin{array}{lcccc}
 & & & & \text{Av.} \\
 & x_1 + a & x_2 + a + b & x_3 + a & \bar{x} + a + b/3 \\
 & x_1' & x_2' + b & x_3' & \bar{x}' + b/3 \\
 & x_1'' & x_2'' + b & x_3'' & \bar{x}'' + b/3 \\
\text{Av.} & \bar{x}_1 + \frac{a}{3} & \bar{x}_2 + b + \frac{a}{3} & \bar{x}_3 + \frac{a}{3} &
\end{array}
$$

These additions alter the standard deviations of both row and column averages. How then will it be possible to form an estimate that has not been altered by these additions? The answer is simple. Form averages by collecting the data according to the following schedule:

A B C	Ave. for A	$\bar{x} + a/3 + b/3$
C A B	Ave. for B	$\bar{x} + a/3 + b/3$
B C A	Ave. for C	$\bar{x} + a/3 + b/3$

Thus all three averages have been increased by the same composite constant quantity $(a+b)/3$ and the averages will yield exactly the same estimate of the standard deviation for these diagonal

averages as was obtained before the addition of the constants.

There remains only the task of indicating how to obtain this estimate of the standard deviation in the general case where the numbers of rows and columns are different. The following symbols will be used

s_r^2 = square of standard deviation computed for r rows = 0.009754

s_c^2 = square of standard deviation computed for c columns = 0.03395

s_t^2 = square of standard deviation computed for all the data. = 0.09792

The last item is computed by ignoring completely the row, column classification. The average for all the measurements is computed. The difference between this grand average and every individual measurement is squared and the sum of these squares is found. This sum when divided by one less than the total number of measurements gives s_t^2.

Compute $(rc-1)\ s_t^2 = 1.9583$

Compute $c(r-1)\ s_r^2 + r(c-1)\ s_c^2 = 0.1366 + 0.6111 = 0.7477$

The difference 1.2106 between these quantities when divided by $(r-1)(c-1)$ or 12 gives $s_I^2 = 0.1009$. This is the estimate of the square of the standard deviation of the individual measurements which is immune from any constant components present in either the rows or columns. Extracting the square root gives 0.3176 for the third estimate of the standard deviation.

Tabulation of Results

Standard Deviation Estimated from		Square of S.D.	F ratio	Critical ratios
Rows	0.2613	0.0683	0.677	3.88
Cols.	0.3191	0.1018	1.009	3.00
Indirectly	0.3176	0.1009		

The F ratios are both near unity and are found to be less than the respective critical values taken from the F table. The critical value for F is found by entering the table at the top with $(c-1)$ and at the left with $(r-1)(c-1)$ for columns. For rows the table is entered at the top with $(r-1)$ and at the left with $(r-1)(c-1)$. The conclusion in this case is that the set of measurements is homogeneous, in other words that the variation among the row averages and also among the column averages is in keeping with the variation of the measurements as revealed by the estimate which is not influenced by any constant row or column effects if present.

If these computations are repeated for the same data after the addition of 1.40 to the entries in the first column, the calculated F ratio for columns becomes 6.16. This is well in excess of 3.00, the five per cent critical value, and even exceeds 4.82, the one per cent critical value. The verdict would then be that there does exist a significant difference among the column averages.

Application to Experimental Results

It is usually the case that the grouping of data into columns and rows corresponds to classifications arising in the experimental work. For example, counts may be made with a Geiger counter on four samples of radium.* If the four samples are run consecutively the four counts may be called Experiment 1. The experiment may be repeated as often as desired varying the order of the samples in each experiment. The results of such an investigation are shown in Table IV which gives the net counting rates per second diminished by 25.00

Table IV

Net counting rates less 25.00

Sample Number	Experiment Number				Sample Average
A	1.46	2.00	1.48	1.51	1.61
B	2.58	3.03	2.82	2.90	2.83
C	4.15	4.61	4.31	4.13	4.30
D	4.54	4.52	4.53	4.15	4.44
Exper. Av.	3.18	3.54	3.28	3.17	

The experimenter is interested to know whether these data constitute evidence of differences between the radium samples. He would also like to know the precision of comparisons between samples.

Inspection shows that the sample averages vary more than the averages for the different experiments. It is possible that the line voltage or other conditions which influence the counting rate varied from experiment to experiment. In that case the variation shown by the experiment averages is greater than would have been the case if all conditions influencing the counting rate could have been held constant over all four experiments. This will be revealed by calculating the estimate of the standard deviation which is independent of any differences between samples or any constant differences between experiments.

Calculating the three estimates of the standard deviation shows that samples and experiments give larger estimates than the diagonal

* H. H. Seliger, A New Method of Radioactive Standard Calibration. Journal of Research of the National Bureau of Standards, 45, 496-502, 1950.

averages. The F ratios exceed the tabulated critical value and supply convincing evidence of differences between samples and persuasive evidence of differences between experiments.

Standard Deviation Estimated from		Square of S.D.		5% level for F*
Samples	2.6719	7.1391	298.7	3.86
Experiments	0.3419	0.1169	4.89	3.86
Diagonals	0.1546	0.0239	-	

*Three and nine degrees of freedom.

It was previously seen that differences between row (sample) averages are unaffected by constant differences between columns (experiments). Consequently the precision of the sample comparisons is not diminished by the existence of such differences between experiments. When the measurements are grouped as above in separate experiments the proper estimate of the precision is obtained from the diagonal averages, in this case, 0.1546. If, as is often done, the precision is calculated directly from the four measurements on sample A, the four on sample B, etc. a larger estimate (0.2168) is obtained. The larger value may lead to overlooking real differences between samples, and does not do justice to the real precision of the work which has been improved by taking the measurements in blocks, here called experiments.

Summary

The whole discussion has been based upon the standard deviation as a measure of variation and the simple rule relating the standard deviation of an average to the standard deviation of the individual measurements entering into the average. Whenever measurements are arranged in a rectangular array it is possible to arrive at three separate estimates of the standard deviation. One estimate is based upon the row averages, a second upon the column averages, and the third upon some complicated diagonal averages so chosen as to be unaffected by constant additions to the entries in the columns or rows. It is logical to expect, if the classification of the data into the rows and columns results in no pattern in the dispersion of the measurements, that the row and column averages will lead to estimates of the standard deviation which are comparable with the third estimate. The statistician has tables of the ratio F to appraise the row and column estimates in terms of the estimate which is immune from constant row or column additions.

All the foregoing describes a rather clumsy bit of arithmetic for reaching the same numerical results (F ratios) that are achieved by a series of neat computations under the heading: The Analysis of Variance.

SOME EXAMPLES OF THE USE OF THE ANALYSIS OF VARIANCE
IN INTERPRETING CHEMICAL DATA FROM THE LABORATORY,
THE PILOT PLANT, AND THE PRODUCTION PROCESS

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The title of this paper specifically refers to the use of the analysis of variance. No attempt is being made at an explanation of the algebraic background which can be found in, for example, Kendall's or Mood's texts, nor of the arithmetical procedures which can be found, for example, in Snedecor or Brownlee. The aim of this paper is to show how the analysis of variance gives simple solutions to problems that would be otherwise well nigh insoluble.

However, we might briefly and approximately outline that what the analysis of variance does is to take the total variance of a set of observations, defined in the usual way, as

$$S^2 = \frac{\sum (x - \bar{x})^2}{n - 1},$$

and analyze it into components attributable to specific effects. The difference between the total variance and the sum of these effects we call the "Residual" and use as error. If the portion due to any particular effect is large, compared with that due to error, then we conclude that that effect is having a real effect on the variable. Our comparison of the variance due to any effect with the variance of the residual will be made with the variance ratio, or F, test, and incidentally we will prefer to call these variances "mean squares."

The first example we have relates to a factorial experiment carried out on the pilot plant scale. A crystalline product was being purified by a form of steam distillation process. The five factors, all at two levels, were:

(a) Concentration of material (= C)
(b) Volume of solution (= V)
(c) Solvent/water ratio (= S)
(d) Stirring rate (= R)
(e) Rate of distillation (= D)

and the residual acidity of material from one run on each of the $2^5 = 32$ experimental treatment combinations was determined. The results, with the decimal point removed for ease of calculation, are in Table I.

Table I

Residual Acidities from a Five Factor Experiment

		C_1				C_2			
		R_1		R_2		R_1		R_2	
		S_1	S_2	S_1	S_2	S_1	S_2	S_1	S_2
D_1	V_1	9	9	11	8	10	3	11	7
	V_2	5	6	7	7	3	5	7	10
D_1	V_1	8	4	9	8	6	6	10	6
	V_2	6	4	7	5	10	3	11	6

This was a five factor experiment without replication, and therefore there is no direct measurement of experimental error. We can decide a priori to use the experiment to determine the 5 main effects and the 10 first order interactions, but to pick out by any sort of inspection which of these 15 possible effects is significant is for practical purposes impossible. There is clearly quite a large experimental error, and for any one observation all 15 supposedly possible effects are superimposed upon it, and this makes the interpretation too difficult.

With the analysis of variance we divide the total variance into a number of components, namely those attributable to the 5 main effects, those attributable to the 10 first order interactions, and the residual. The residual is obtained here as the difference between the total and the items we have explicitly calculated. It is actually made up of the 10 second order interactions, the 5 third order interactions, and the fourth order interaction, together with the experimental error. However, we decide a priori that an experiment of this size is unlikely to provide reasonably accurate estimates of the higher order interactions, and furthermore these higher order interactions are unlikely to be either real or of interest. Accordingly we leave them pooled with the residual as error.

Table II

Analysis of Variance of Data in Table I

Source of Variance	Degrees of Freedom	Sums of Squares	Mean Squares
R = Stirring rate	1	34.031	
D = Rate of distillation	1	2.531	
C = Concentration	1	0.031	
S = Solvent/water ratio	1	34.031	
V = Volume of solution	1	16.531	
R x D	1	0.281	
R x C	1	3.781	
R x S	1	0.031	
R x V	1	0.281	
D x C	1	5.281	
D x S	1	9.031	
D x V	1	5.281	
C x S	1	3.781	
C x V	1	7.031	
S x V	1	5.281	
Residual	16	55.604	3.475
TOTAL	31	182.719	

The analysis of variance of the data in Table I is in Table II. The variance ratio test tells us that any mean square exceeding the residual mean square by the ratio 4.49, i.e. mean squares of 15.6 or greater, will be significant at the 0.05 level. The corresponding figures for the 0.01 level of significance are 8.53 and 29.6 respectively.

Inspection of Table II shows, using these criteria, that the R and S main effects are significant at the 0.01 level and the V main effect is significant at the 0.05 level. The other main effects and all 10 of the first order interactions are non-significant.

The uses of the analysis of variance here have been twofold:

(a) It gave us an estimate of the residual or error mean square as 3.475, corresponding to a standard error of 1.864.

(b) Against this error mean square the variance ratio test immediately identified those factors which were significant.

The next step would be to calculate the average effects as R = +2.06, S = -2.06, and V = -1.44 (for the mean of the higher level minus the mean of the lower level). The standard error of these differences will be in every case $\sqrt{2} \times 1.864/\sqrt{16} = 0.5271$ and the 95% confidence limits will be obtained by multiplying the standard error by Student's t for the degrees of freedom for the residual (16) and the 0.05 significance level, namely 2.12. These confidence limits are thus ±1.12.

This completes the analysis of the experiment. The point I am trying to make is that without the analysis of variance we could have made very little of the data - with it we reach by an easy route quite definite and intelligible conclusions.

Our second example is based on the data in Table III. We have duplicate measurements on duplicate samples from a chemical process. Let us assume that it costs t dollars to make an analysis, and kt dollars to obtain a sample. From the data in Table III we wish to find out what is the most economical system of sampling and analysis. For example, we might make single analyses on several samples or we might make several analyses on a single sample, or we might have some intermediate arrangement.

Table III

Duplicate Analyses on Duplicate Samples from 26 Batches

Batch	1		2		3		4	
Sample	A	B	A	B	A	B	A	B
Analyses	88.99	88.87	88.47	88.50	87.04	87.01	85.33	85.32
	88.89	88.86	88.43	88.51	86.98	86.96	85.35	85.32
Batch	5		6		7		8	
Samples	A	B	A	B	A	B	A	B
Analyses	84.27	84.48	86.90	86.85	83.23	83.34	86.19	86.26
	84.29	84.41	86.90	86.77	83.34	83.21	86.21	86.26
Batch	9		10		11		12	
Samples	A	B	A	B	A	B	A	B
Analyses	86.84	86.78	88.67	88.63	88.72	88.74	85.48	85.52
	86.78	86.90	88.57	88.64	88.60	88.67	85.45	85.53
Batch	13		14		15		16	
Samples	A	B	A	B	A	B	A	B
Analyses	88.14	88.25	83.43	83.47	85.48	85.64	82.23	82.34
	88.15	88.20	83.49	83.40	85.50	85.69	82.04	82.20

Table III - Cont'd.

Batch	17		18		19		20	
Samples	A	B	A	B	A	B	A	B
Analyses	83.23	83.15	86.02	86.16	88.91	88.71	88.66	88.75
	83.09	83.03	86.09	86.13	88.84	88.86	88.74	88.64

Batch	21		22		23		24	
Samples	A	B	A	B	A	B	A	B
Analyses	85.15	85.23	88.08	88.02	82.43	82.52	84.72	84.82
	85.23	85.19	88.11	88.04	82.36	82.66	84.74	84.78

Batch	25		26	
Samples	A	B	A	B
Analyses	82.52	82.45	85.57	85.50
	82.30	82.41	85.52	85.47

The analysis of variance is in Table IV.

Table IV

Analysis of Variance of Data in Table III

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares	Components of Variance
Between Samples	0.188375	25	0.007535	$s_a^2 + 2s_s^2$
Between Analyses	0.176950	78	0.002269	s_a^2
Total		103		

To test whether s_s^2, the component of variance due to sampling, is significantly greater than zero, we test the Between Samples Mean Square against the Between Analyses Mean Square with the variance ratio, or "F" test. Here we obtain F = 3.32 and for these degrees of freedom this is highly significant ($P < 0.001$). We therefore conclude s_s^2 exists (i.e. is greater than zero) and proceed to calculate it from the equations:

$$s_a^2 + 2s_s^2 = 0.007535$$

$$s_a^2 = 0.002269$$

whence,

$$s_s^2 = 0.002633$$

We now have the general situation that for the mean of a analyses the variance due to analysis will be s_a^2/a. In addition there will be the variance of the sample itself, s_s^2, so the total variance will be,

$$s_s^2 + s_a^2/a \qquad (1)$$

If we take n samples and perform a analyses on each of them and take the overall means it will have a variance, defined as s_M^2, as

$$s_M^2 = (s_s^2 + s_a^2/a)/n = s_s^2/n + s_a^2/na \quad (2)$$

Now let us consider the problem of adjusting the relative values of n and a to give the minimum variance for any total expenditure. If we make a analyses at t dollars an analysis on each of n samples at kt dollars a sample, our total cost is

$$T = nkt + nat \qquad (3)$$

which gives us

$$\begin{aligned} na &= (T-nkt)/t \\ &= (T/t) - nk \end{aligned} \qquad (4)$$

Substituting this in (2) gives us

$$s_M^2 = s_s^2/n - s_a^2/[(T/t) - nk] \qquad (5)$$

We now proceed to assume that s_s^2 and s_a^2 are fixed, as is k (the ratio of the costs of sampling compared with analysis), and we wish to find the value of n that will make s_M^2 a minimum. To do this we differentiate with respect to n and equate to zero:

$$\frac{d(s_n^2)}{dn} = \frac{-s_s^2}{n^2} + \frac{ks_a^2}{[(T/t) - nk]^2} = 0 \qquad (6)$$

Proceeding to rearrange this, we have

$$\frac{s_s}{n} = \frac{\sqrt{k}\ s_a}{(T/t) - nk} \qquad (7)$$

or

$$\sqrt{k}\ n\ (s_a/s_s) = (T/t) - nk \qquad (8)$$

But from (4),

$$(T/t) = na + nk \qquad (9)$$

which gives us

$$\sqrt{k}\ n\ (s_a/\ s_s) = na \qquad (10)$$

or

$$a^2 = k\,\frac{s_a^2}{s_s^2} \qquad (11)$$

We can now apply equation (11) to our specific example. We had $s_a^2 = 0.002269$, $s_s^2 = 0.002633$, and k was for this system equal to 2 (i.e. it cost twice as much to obtain a sample as to make a single analysis of it when we had got it). Inserting these values we get,

$$a^2 = 2 \times 0.002269/0.002633 = 1.724$$

or

$$a = 1.313.$$

Of course, a has to be a whole number, so we should take a as 1. For this particular system, therefore, the most economical arrangement is to

make single analyses on each sample, and the total number of samples taken will of course be chosen to give us the accuracy we need. For example, if we required 95% confidence limits of 0.10 for our mean, then the standard deviation of the mean would be 0.10/1.96 = 0.05102 and the number of samples necessary would be given by

$$(s_s^2 + s_a^2)/n = (0.05102)^2.$$

With our values for s_s^2 and s_a^2 this gives n = 5.20, so the minimum number to satisfy our requirements would be 6.

Table V gives the variance of the mean for a number of possibilities. Values of s and a were selected such that the total cost equalled 12 t. As indicated above, the arrangement giving minimum variance is that with 1 analysis per sample.

Table V.

Number of Samples	Number of Analyses per Sample	Cost in Units of t	Variance of Mean
s	a	2s + as	$\frac{s_s^2}{s} + \frac{s_a^2}{as}$
1	10	1 x 2 + 10 x 1 = 12	0.002860
2	4	2 x 2 + 4 x 2 = 12	0.001600
3	2	3 x 2 + 2 x 3 = 12	0.00126
4	1	4 x 2 + 1 x 4 = 12	0.00123

$$s_s^2 = 0.002633, \quad s_a^2 = 0.002269$$

In any particular case, the value of a will depend on the ratio of the analytical to the sampling variance and on the value of k, the ratio of the cost of sampling to the cost of analysis. In Table V the optimum number of analyses per sample is calculated for certain typical values of the ratio of sampling variance to analytical variance (s_s^2/s_a^2) and of the ratio of cost of sampling to cost of analysis. The irrational entries are, of course, rather meaningless as one cannot perform, for example, 1.414 analyses per sample, but they are included to add to the general impression.

Table VI

The Optimum Number of Analyses per Sample (a) for Given Values of the Ratio of Sampling Variance to Analytical Variance (s_s^2/s_a^2) and of the Ratio of Cost of Sampling to Cost of Analysis (k).

s_s^2/s_a^2 \ k	1/4	1/2	1	2	4	8
1/4	1	$\sqrt{2}$	2	$2\sqrt{2}$	4	$4\sqrt{2}$
1/2	$(1/\sqrt{2})$	1	$\sqrt{2}$	2	$2\sqrt{2}$	4
1	(1/2)	$(1/\sqrt{2})$	1	$\sqrt{2}$	2	$2\sqrt{2}$
2	$(1/2\sqrt{2})$	(1/2)	$(1/\sqrt{2})$	1	$\sqrt{2}$	2
4	(1/4)	$(1/2\ \sqrt{2})$	(1/2)	$(1\sqrt{2})$	1	$\sqrt{2}$

The entries less than unity are interesting. Consider, for example, the entry for $(s_s^2/s_a^2) = 4$, k = 1/4. Here the sampling variance is large compared with the analytical variance and the cost of analysis is

large compared with the cost of sampling. How, you may ask, can one perform 1/4 analyses per sample. The answer, of course, is by blending. Table V shows that under these conditions we would maximize our information per dollar by taking 4 samples, blending them, and performing one analysis on the blended sample.

Let us consider the efficiency of such a procedure compared with single analyses per sample. If the cost of a single analysis is t, then since $k = 1/4$, the cost of a sample is $t/4$. The total cost of obtaining, say, 20 samples and performing 5 analyses on the blended material will be $(20 \times t/4) + 5t = 10\,t$ and the variance of the mean will be

$$s_s^2/20 + s_a^2/5 = 4s_a^2/20 + s_a^2/5 = 2s_a^2/5,$$

since $s_s^2 = 4s_a^2$. The total cost of 8 analyses on 8 samples will be $(8t/4) + 8t = 10t$, the same as before, and the variance of its mean will be

$$s_s^2/8 + s_a^2/8 = 4s_a^2/8 + s_a^2/8 = 5s_a^2/8$$

The ratio of the variance of this latter arrangement to the former will be

$$(5s_a^2/8)/(2s_a^2/5) = 25/16 = 1.5625.$$

The variance of the blending procedure is then about two-thirds that of the single analysis per sample procedure. The practicality of the blending procedure depends, of course, on the ease with which it can be carried out with complete accuracy. In the case of liquids or solids which can conveniently be put into solution there is no difficulty at all. For other solids, e.g. powders, which cannot be put into solution, greater care would be necessary.

I have discussed this example at some length because it is a basis for illustrating the desirability of introducing a little science into this sampling business. We should know the main properties of the procedure we are following, and how far it deviates from the optimum and how a figure derived from it is likely to be in error. Quite frequently the analytical variance is recognized and evaluated, but the sampling variance is overlooked, whereas quite often it will be the more important item. To study these relations is another function of the analysis of variance.

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SOME RAPID APPROXIMATE STATISTICAL PROCEDURES

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The widespread use of the Shewhart control chart is due in part at least to the simplicity of the calculations involved, and the ease with which these calculations may be performed, even by those with little mathematical training. On the other hand statistical techniques such as the analysis of variance are more time-consuming, and usually require the use of a calculating machine and considerable training in statistical methods.

While the usual statistical tests of significance depend on the use of squared deviations, there has been much interest recently in tests based on order or relative rank of the measurements, and such tests are very easy to make, and are often sufficiently sensitive for the purpose in view.

Unpaired Comparisons

As an example of such a test we may consider the following series of measurements, (1), of the tensile strength of steel strand, derived from two different manufacturers, A and B. There are 40 values in all, 20 from the product of manufacturer A and 20 from B, and it is desired to test whether the results are consistent with the idea that there is no difference in tensile strength between the products of the two firms.

The 40 measurements may be arranged in increasing order as follows, the data being expressed in thousands of lbs. per sq. inch:

12.6A(1), 13.11A(2), 13.18B(3), 13.25A(4), 13.26B(5), 13.32A(6), 13.37A(7), 13.39B(8), 13.40A(9.5), 13.40B(9.5), 13.43A(11), 13.44A(12.5), 13.44A(12.5), 13.51A(14), 13.55A(15), 13.57A(16.5), 13.57A(16.5), 13.61B(18), 13.75A(19), 13.79B(20), 13.80A(21), 13.81B(22), 13.86A(23), 13.90A(24.5), 13.90B(24.5), 13.91B(26.5), 13.91A(26.5), 13.96A(28), 13.99B(29), 14.13B(30), 14.14B(31), 14.17B(32), 14.25B(33.5), 14.25A(33.5), 14.29B(35), 14.30B(36), 14.46B(37), 14.48B(38), 14.55B(39.5), 14.55B(39.5).

The figures in parentheses are the ranks or serial numbers, and where tied values occur, the average of the two ranks is assigned to each.

The sum of all the A ranks is 303, and that of the B ranks is 517. The total sum of all ranks is 820, and if the two kinds of materials did not differ, it would be expected that the rank total for each kind would be somewhere near 410.

The question to be decided is whether a value for one of the totals of 303 is improbable if the two materials were the same. This point can be decided by referring to published tables (2) in which the critical totals corresponding to probabilities of .05, .02, and .01 are given.

According to these tables the probability of a rank total of 315 or less is .01, and therefore the probability of getting 303 or less must be less than .01, and it is therefore quite justifiable to conclude that the two materials are different in tensile strength.

The tables mentioned above do not provide for comparing more than 20 replicate values under each of the two groups being compared. However, when the number of values is more than 20, the distribution of the rank totals is practically normal with a standard deviation equal to $\sqrt{N\bar{T}/6}$; where N is the number of replicate values in each group, $\bar{T}$ is the expected rank total for each group and is equal to $2N(2N+1)/4$. Thus the probability of obtaining any particular rank total by chance may be found by forming the ratio ($\bar{T}$-Tobs.)/St.Dev. and referring to tables of the normal probability curve. Even when we have to deal with unequal numbers of observations in the two groups a similar procedure may be followed. If there are N_1 values in one group and N_2 in the other and we let $N=N_1+N_2$, the expected rank total $\bar{T}$ for N_2 is $N_2(N+1)$, and the standard deviation is $\sqrt{N_1\bar{T}/6}$, so that a test of significance is possible here also.

Paired Comparisons

Many comparisons of two groups or categories occur in pairs, as for example when two analytical methods are compared on a number of different samples, and each sample is analyzed by both methods. By taking the differences between the results by the two methods and arranging these differences in increasing order neglecting the sign of the difference, a simple rank method may be used to decide if the mean difference is significantly different from zero.

In a comparison of a chemical method for determination of potassium with a method depending on measurement of radioactivity with a Geiger counter the following differences in per cent K_2O were obtained on 14 samples (2):

0.1(1.5), -0.1(-1.5), 0.2(4.0), -0.2(-4.0), -0.2(-4.0), -0.6(-6.5), -0.6(-6.5), -0.7(-8.0), -0.8(-9.0), -0.9(-10.0), 1.0(11.5), -1.0(-11.5), 1.2(13.0), 1.2(14.0).

As before the figures in parentheses are rank numbers assigned to the differences, and the ranks receive the same sign as the differences to which they correspond. By adding together the positive ranks we arrive at a total of 44, while the negative ranks add up to a total of -61.0. The sum of all the ranks is 105, and if the two methods gave in the long run the same results it would be expected that the positive and negative ranks would give totals not far from 52.5 and -52.5. The tables mentioned previously enable us to decide whether the positive total of 44 is sufficiently low as to justify a decision that the two methods differ on the average.

In this case a total of 21 or less would correspond to a probability of 0.05, so there is little reason to think that the total of 44 obtained indicates a significant difference.

The tables give probabilities for numbers of paired values from 6 to 25. In case it is necessary to deal with more than 25 values the following procedure may be followed:

The frequency distribution of the rank total of one sign is considered to be a normal distribution with standard deviation equal to $\sqrt{(2N+1)\bar{T}/6}$, where N is the number of pairs and $\bar{T}$ is the rank total expected and is equal to $N(N+1)/4$.

Comparison of Several Groups

The two rank methods described above are useful in the cases where only two groups or categories are being compared. However, we frequently have to deal with a situation where there are several groups and a decision must be reached as to whether these groups differ in general.

A method suitable for such a test was described a number of years ago by Friedman (4). The method may be illustrated by some pilot plant data from a catalytic cracking unit (5).

The following table gives carbon yields in per cent for 6 test periods and 4 different numbers of cycles for test period:-

Cycles per Test Period

8	Rank	12	Rank	24	Rank	32	Rank
4.28	(2.0)	4.34	(3.0)	4.84	(4.0)	4.15	(1.0)
4.37	(3.0)	4.35	(2.0)	5.18	(4.0)	4.21	(1.0)
4.25	(1.0)	4.35	(2.0)	4.43	(4.0)	4.39	(3.0)
4.40	(2.0)	4.11	(1.0)	5.15	(4.0)	4.59	(3.0)
4.54	(3.0)	4.38	(2.0)	4.85	(4.0)	4.35	(1.0)
5.19	(3.0)	4.38	(1.0)	5.24	(4.0)	4.60	(2.0)
	14.0		11.0		24.0		11.0

The yield values have been assigned ranks or scores from 1 to 4 for each test period and the total scores for each number of cycles for test period are given at the bottom of the table.

A value called Chi-squared (r) may be calculated from these totals together with the number of cycles (p) and the number of tests under each number of cycles (n) as follows:-

$$\text{Chi-squared } (r) = \frac{12\ S(T)^2}{np(p+1)} - 3n(p+1)$$

$S(T)^2$ is the sum of the squares of the score totals, in this case 1014. n is 6 while p is 4. We have then:-

$$\frac{12 \times 1014}{24 \times 5} - (18 \times 5) \text{ or } 11.4$$

The approximate probability of obtaining such a value of Chi-squared (r) may be read from tables or charts of the Chi-squared distribution and is 0.01. We are justified then in concluding that the number of cycles affects the carbon yield. The number of degrees of freedom for entering the table of Chi-squared is p-1 or 3 in this case.

Theoretical Basis of Rank Tests

The possibility of using the rank test for unpaired comparisons may be understood by considering the following situation. Suppose we had a box containing 40 chips numbered consecutively from 1 to 40. Suppose now that these chips were well mixed and twenty withdrawn at random, and the total of the numbers on the chips withdrawn were recorded. If this procedure were repeated a very large number of times, and a record kept

of the rank totals, it would be found that the totals obtained would fluctuate around the expected total of 410 in a definite manner. Each rank total which could be obtained would have a probability of occurrence which would depend on the number of ways of combining 20 ranks so that they would add up to the total in question. This number would increase from 1 way for the lowest possible total of 210 to a rather large number of ways for 410, and finally decrease to 1 way for the highest possible total of 610. Since the number of ways of obtaining each total may be calculated, it is possible to find the probability of obtaining any particular total or a lower one.

A mathematical model of similar type may be imagined for the rank test of paired comparisons. This model leads to a frequency distribution somewhat different in form from that for the unpaired case, but like the latter, it approaches the normal distribution as the number of cases considered increases indefinitely.

There is of course some loss of information involved in dealing with ranks or scores instead of the actual data, but this is usually more than offset by the ease and rapidity with which the tests of significance may be applied. Experience with these tests has shown that they are adequate for most situations, and they have the advantage that no assumptions need be made regarding the normality of the population from which the sample is drawn.

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QUALITY EVALUATION OF GENERAL ELECTRIC COMPANY'S ARINC TUBES

J. Alfred Davies
General Electric Company

High Reliability of ARINC Tubes

High reliability is the keynote of the Owensboro Tube Works' program for developing and producing the General Electric five-star ARINC tubes. This program was initiated by Aeronautical Radio, Inc. for the specific purpose of increasing the dependability of electronic equipment used in aircraft for both navigation and radio communication. Reliability of electron tubes and components is a "must" for aircraft operation. Hence, the ARINC tube program is a natural for quality control. The Owensboro Tube Works, as a supplier of high-reliability ARINC tubes, recognizes the value of quality control as the tool for attaining the dependability required.

Illustration 1 shows the line of ARINC tubes presently in development or in production. These tube types are similar in function to conventional types, including a twin diode, twin triodes with high or low Mu, R-F amplifier pentodes with remote or sharp cutoff, a pentagrid converter, and a gas-filled tetrode thyratron. However, their constructions have been made more rugged by structural design and assembly processes.

Quality Control in the Program

Applications of quality control extend throughout all stages of design, development, production, inspection, and application of these tubes. Quality control for high-reliability starts with the initial concept of a tube type and follows through the analysis of tubes in service, including the following main phases:

1. Objective specification;
2. Material and construction specification;
3. Test specification;
4. Production processing and assembly;
5. Quality acceptance specification; and
6. Analysis of field results

Objective Specification

The requirements of the tube's application in electronic equipment determine the reliability features. It is desired to produce a tube type which will have the following features:

1. Ability to withstand extreme conditions of vibration and shock without tube failures and with very little change of electrical characteristics;
2. Well controlled centering of the critical and major electrical characteristics; and
3. Operation over a specified period of time with a minimum failure rate particularly during early-life period.

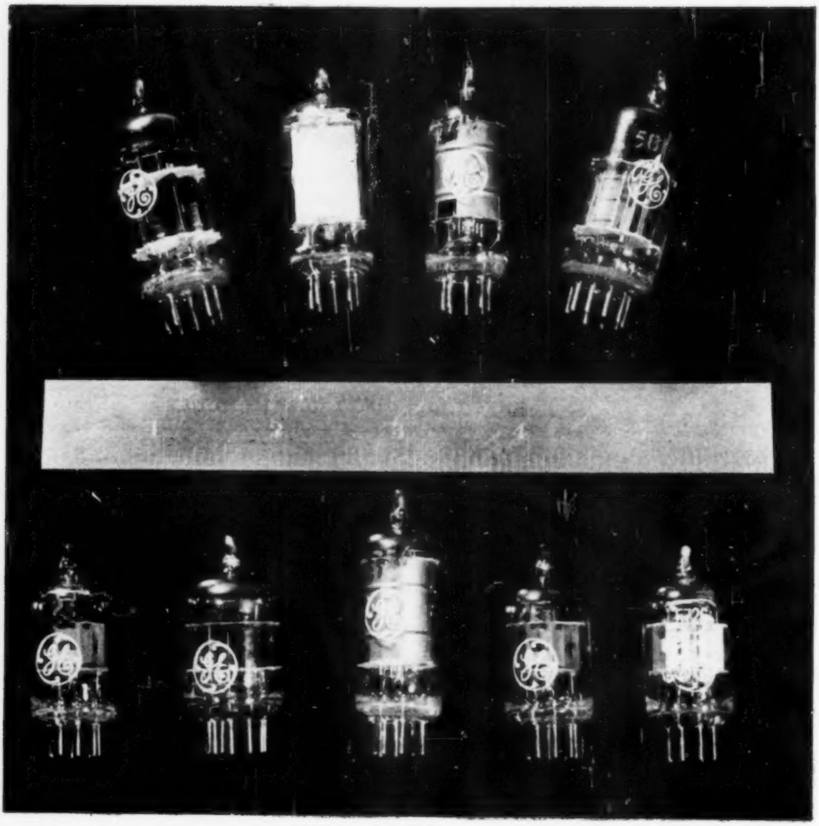


ILLUSTRATION I

Most of these features can be written into the objective specification to show the level or degree of severity required for the electrical or vibration items. The electrical characteristics are considered from previous experience with respect to the tube function as a converter, R-F amplifier, power output, etc. However, some of the reliability features are the so-called "quality characteristics" which cannot be specified in terms of an objective for the design only, since they are more dependent on processing. Consideration is given to these quality characteristics in the test specification.

Material and Construction Specification

After the objectives have been established the design engineers begin development of the tube type, testing each part of the structure for its mechanical strength and effects on electrical characteristics. Here again quality control proves helpful in applying techniques for designing experiments, testing the pilot runs for significant differences, correlating electrical characteristics and determining the relative effects and interactions of various combinations of parts. Data are kept for all the usual electrical and quality characteristics and also for any items which give unusual results during the development.

Finally, tolerances are set and the material and construction specifications are written for the finished design. Statistical control methods are used to evaluate the final design for approval prior to a production run. Analysis of data from the tests for design approval gives information concerning the expected product center, dispersion and nature of frequency distribution, all of which are essential to the following step.

Test Specification

Development of the test specification for the tube type provides a tough proving ground for quality control. In this specification the reliability features of the objective specification must be translated into meaningful tests of both electrical and mechanical nature. Also, the "quality characteristics" are included. Then all test items are classified as production, special design, or standard design tests which are practically the equivalents of critical, major, and minor tests which are assigned AQL's of 1%, 4%, and 8%, respectively. Illustration 2 shows the classification of electrical tests for type 5670, a typical ARINC twin triode. The nature of the distribution of each test item is given also since these items are subjected to acceptance sampling by variables as well as by attributes.

Other test items which are tested by attributes only have been termed Special Tests and are shown in Illustration 3. Base strain and shock tests have been assigned AQL's of 10% and 20% respectively, since they are destructive tests and considerably more severe than actual operating conditions. The increased severity and higher AQL levels are required to magnify the per cent defective in the sample so that relatively small samples may be used for these destructive tests by attributes.

Production Processing and Assembly

Production processing and assembly call for controls establish d from

CLASSIFICATION OF TEST ITEMS
ELECTRICAL TESTS
TYPE 5670

Test Item	Symbol	Classification	AQL	Nature of Distribution
Grid Current	$-I_{gl}$	Production Test	1%	J-Shape, O Center
Plate Current	I_p	Production Test	1%	Normal
Transconductance	S_m	Production Test	1%	Near Normal
Heater - Cathode Leakage	I_{hk}	Special Design Test	4%	J-Shape, O Center
Heater Current	I_f	Special Design Test	4%	Normal
Plate Current Cutoff	I_pC_o	Special Design Test	4%	J-Shape, O Center
Microphonics	E_p	Special Design Test	4%	Skewed Positively
Transconductance at Reduced E_f	S_mR	Special Design Test	4%	Skewsd Negatively
Vibration	Vib	Standard Design Test	8%	J-Shape, O Center
Amplification Factor	Mu	Standard Design Test	8%	Normal
Grid Emission	I_{sgl}	Standard Design Test	8%	J-Shape, O Center
Capacitance, Grid - Plate	C_{gp}	Standard Design Test	8%	Normal
Capacitance, Input	C_{in}	Standard Design Test	8%	Normal
Capacitance, Output	C_{out}	Standard Design Test	8%	Normal
Capacitance, Plate - Plate	C_{pp}	Standard Design Test	8%	Skewed Positively

ILLUSTRATION 2

CLASSIFICATION OF TEST ITEMS
SPECIAL TESTS
TYPE 5670

Test Item	Symbol	Classification	AQL
Shorts and Continuity	S & C	Special Test by Attributes	3/4%
Base Strain	–	Special Test by Attributes	10%
Shock	–	Special Test by Attributes	20%
Electrode Insulation	IR	Special Test by Attributes	8%
R-F Noise	RFN	Special Test by Attributes	2%

ILLUSTRATION 3

STANDARD AND SPECIAL DESIGN TEST
SAMPLING INSPECTION PLANS

NORMAL INSPECTION:

LOT SIZE	SAMPLE SIZES			STANDARD DESIGN ACCEPTANCE NOS.		SPECIAL DESIGN ACCEPTANCE NOS.	
	FIRST	SECOND	COMBINED				
N	n1	n2	n1 ≠ n2	c1	c2	c1	c2
31 – 500	15	15	30	1	4	1	2
501 – 1000	15	25	40	1	5	1	3
1001 – 2000	16	30	46	1	6	1	3
2001 – 5000	18	35	53	1	7	1	4
5001 – 10000	20	45	65	1	8	1	4

REDUCED INSPECTION:

31 – 200	5	5	10	0	1	–	–
201 – 10000	7	14	21	0	2	–	–
31 – 200	5	10	15	–	–	0	1
201 – 10000	7	14	21	–	–	0	1

Note: For any lot size, the sample sizes and acceptance numbers specified for any larger lot size may be used to simplify the operational and clerical administration.

ILLUSTRATION 6

the relationships between the test specification and tolerances of materials, machine operations and the production operators themselves. Illustration 4, Flow Chart of Production Operations, will be helpful at this point. This chart shows the major steps in the production and the points at which process controls and/or acceptance sampling inspections are performed. Type 5670 is illustrated with actual parts used in the production operations. Without going into details the production procedures can be described as follows:

Incoming materials, both fabricated parts and raw materials for fabrication, are subjected to acceptance sampling before going into materials stock. Also, engineering tests and life tests are run to approve new "melt lots" of metals. Then these materials are processed and/or subassembled in the four main manufacturing sections: Stem manufacturing, grid winding and forming, parts stamping and forming, and chemical preparations and applications. Processed parts and subassemblies from the grid, parts and chemical sections are combined into the "cage" assembly which is welded to the stem to form the finished "mount." The mount is sealed into a tubulated bulb and this assembly is evacuated to produce a high vacuum prior to sealing off the bulb. The tubes are "aged" for a few minutes with various voltages applied to the elements in order to stabilize the electrical characteristics. Then the tubes are tested 100% for inoperatives (open elements, shorted elements, air leaks, gas content, etc.) and whatever electrical characteristics appear questionable on the quality records.

<u>In-Process Inspection and Controls</u>

At each section in the manufacturing process the parts or assemblies are subjected to sampling inspection for acceptance of the production prior to its shipment to the next section. In addition there are in-process controls as follows:

1. Stems
   Control charts (p-chart) for per cent defective stems are used on each machine.
      Out-of-control points on any chart may be traced to one of the 24 heads of the machine by means of the head number on the stem.

2. Grids
   Control charts ($\bar{x}$, R) for average and range of the major and minor outside diameters are used for each grid winding machine. Per cent of visual defects are recorded on p-charts for each machine.

3. Other Parts and Chemical Applications
   Control charts ($\bar{x}$, R) for thickness of the heater insulation coating and the overall length of the heater are used for each heater winding machine.
   Control charts (M, R) are used for median and range of the sprayed weight of the cathode emissive coating.

4. Mount Assembly
   Visual inspection of cages and finished mounts is performed separately under a binocular microscope by two inspectors per assembly unit.

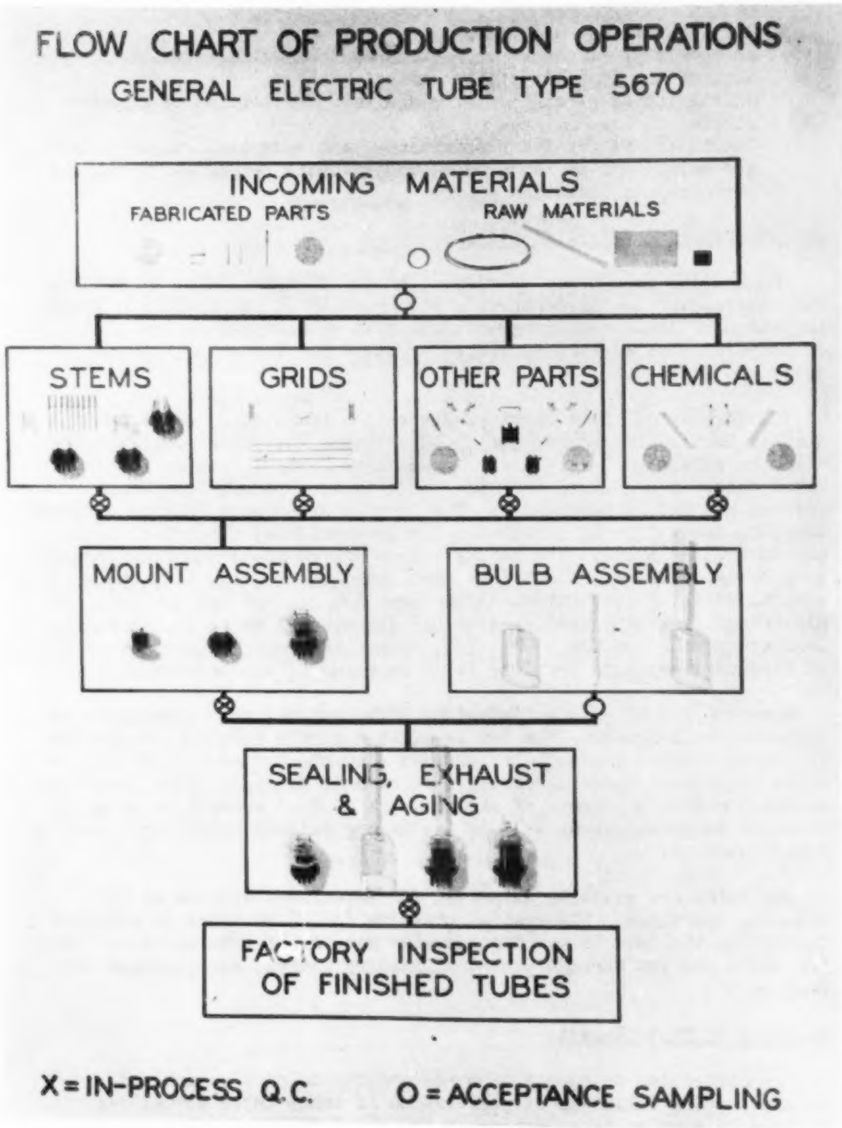


ILLUSTRATION 4

5. Sealing, Exhaust and Aging
An hourly "port check" is made to control exhaust treatment by each of the 16 heads of the exhaust machine.
Charts ($\bar{x}$) of strain patterns are used for control of glass strain.
Charts ($\bar{x}$, R) for transconductance, the essential characteristic, are maintained at the exhaust machine both before and after the 48-hours stabilization period.

__Quality Acceptance Specification__

The quality acceptance specification for finished tubes is written with the accent on the consumer's requirements of reliability. Interpretation of these requirements shows that we must stress our controls of inoperatives, electrical characteristics for centering, special tests and life test.

Illustration 5, Flow Chart of Inspection Operations, shows how the quality control procedures for finished tubes fit these requirements into the acceptance operation. The Quality Control Section for finished tubes is organized into two subsections, Product Acceptance Section and Rating Laboratory. The Product Acceptance Section performs sampling inspection by attributes for inoperatives, electrical tests and mechanical tests. The Rating Laboratory conducts sampling inspection by variables for electrical test items, as well as life tests, and special tests by attributes. After each lot has met the criteria for electrical centering (median control) and special tests at the Rating Laboratory and then the electrical, mechanical, and inoperatives tests at Product Acceptance Section, it is released to the warehouse.

Upon completion of a satisfactory life test the warehouse stock is released for shipment. The lot is given a single sampling inspection for glass cracks, gas and air, shorted elements and continuity of circuits to control these inoperative defects to ½% AOQL. This inspection serves the double purpose of checking the product acceptance sampling test for inoperatives as well as disclosing defects which might develop during storage.

All tubes are visually inspected for appearance defects at the branding operation. The special branding for ARINC tubes is designed for aiding the user in keeping accurate records of tube service. Then the tubes are put through pin-straightening gauges, are packaged and shipped.

__Analysis of Field Results__

Our obligation to supply high-reliability tubes does not end with shipment. The follow-up of performance of tubes under actual conditions in service is an extremely important factor in this program for continuing improvement. Analysis of tube failures in operation points the way for correction of the present product and guides the development of future tubes. The data for analysis are obtained in the following manner:

Each tube is dated at the time it is put into service in airborne electronic equipment. Any failing tube is immediately removed from the equipment and the date of failure is marked on the tube which is

FLOW CHART OF INSPECTION OPERATIONS

GENERAL ELECTRIC TUBE TYPE 5670

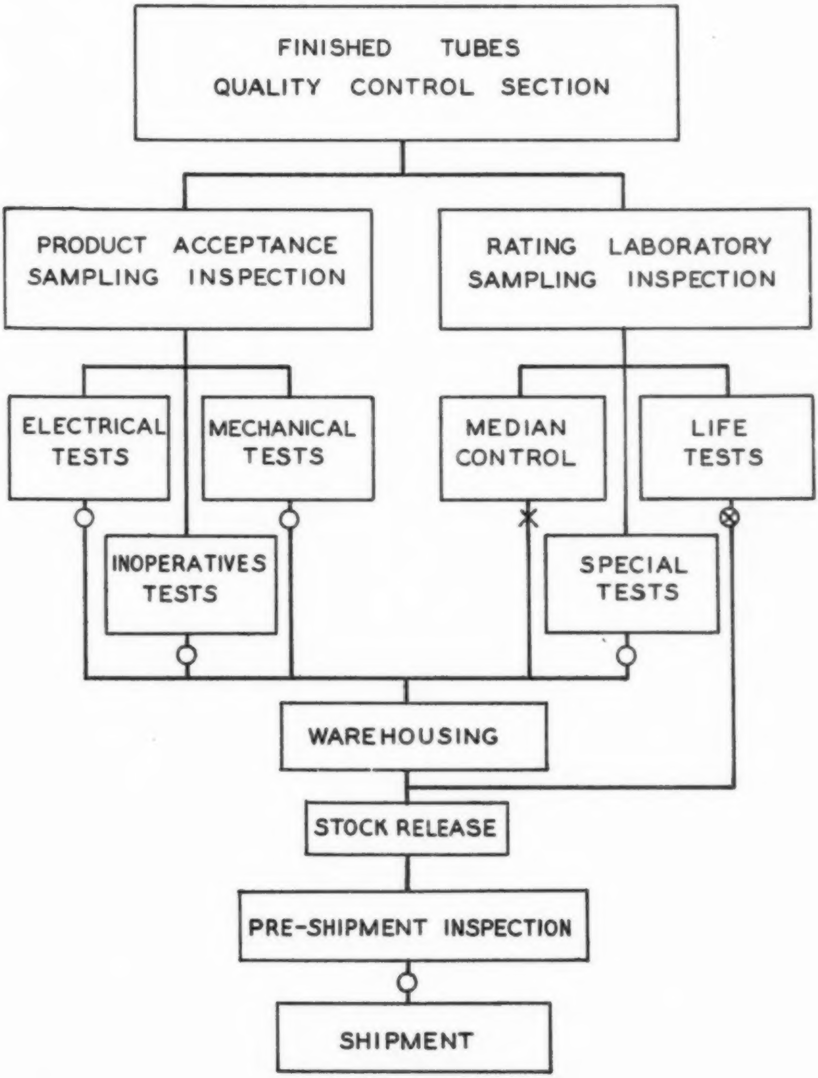


ILLUSTRATION 5

X = ACCEPTANCE BY VARIABLES SAMPLING
O = ACCEPTANCE BY ATTRIBUTES SAMPLING

sent into ARINC Headquarters in Washington, D. C. There it is tested and classified according to the type of failure. A complete summary of time of operation, types of failures and percentage of all failures is prepared by ARINC and forwarded through the Commercial Engineer to the Design Engineering Section of the Owensboro Tube Works. The tubes which fail are also returned to the Design Engineering Section.

These tubes are checked at the Product Acceptance Section for all test items on the test specification sheet. The results of the tests are summarized and circulated to the Design Engineer, Works Engineer, and Commercial Engineer. This summary shows the findings of the tests at Owensboro Tube Works in comparison to those made by ARINC. All types of tube failures resulting from production assembly or processing are referred to the Works Engineer and the Section Engineer in charge of ARINC tubes. Any unusual items are referred to Design Engineering for investigation and correction. Analysis of every possible type of failure is made to determine the nature and cause of such defects.

Records are also analyzed to determine if any equipment or tube socket shows excessive failures which might be traced to equipments rather than tubes. Periodically personnel representing ARINC and Owensboro Tube Works meet to study the summary of quality indices which are used to plan future action for improving tubes.

Evaluation of Finished Tube Quality

The acceptance tests for electrical, mechanical, special, and inoperatives items are performed on the basis of attributes, using standard double sampling tables. Illustration 6 is an example of design tests. Consequently, only the most important one of these, the sampling plan for inoperatives, will be discussed in order that the acceptance tests by variables may be described.

First, the control for centering, known as the median control test, is performed. A sample of 20 tubes is selected at random from the daily production lot in such a manner as to include tubes from at least 4 different hours of production during any shift. This sample is tested for all electrical characteristics and the measurements are recorded on a specially designed sheet for this tube type.

Illustration 7 shows the form used for type 5670. Each electrical test item is shown on the sheet in a small graphical arrangement with the abscissa scales previously designated. The specified center values, known as bogies, are lined up one under another for the purpose of making a quick estimate of correlation of various test items. The solid lines mark the tolerance limits for individual tube measurements. Short dashed lines denote the normal reject limits for the median of any sample, and short dash-dot lines denote the stricter reject limits for the median.

After the 20 measurements have been recorded on the "nearest to" basis, the median value is marked in as a small red dot. If the median falls within the reject limits, the lot is considered acceptable for the test item. However, if the median falls outside of either reject limit, a second sample of 30 tubes is selected at random from the lot and tested for the non-conforming test item(s) only. Then the median of the combined samples, 50 tubes, is determined and marked in on the

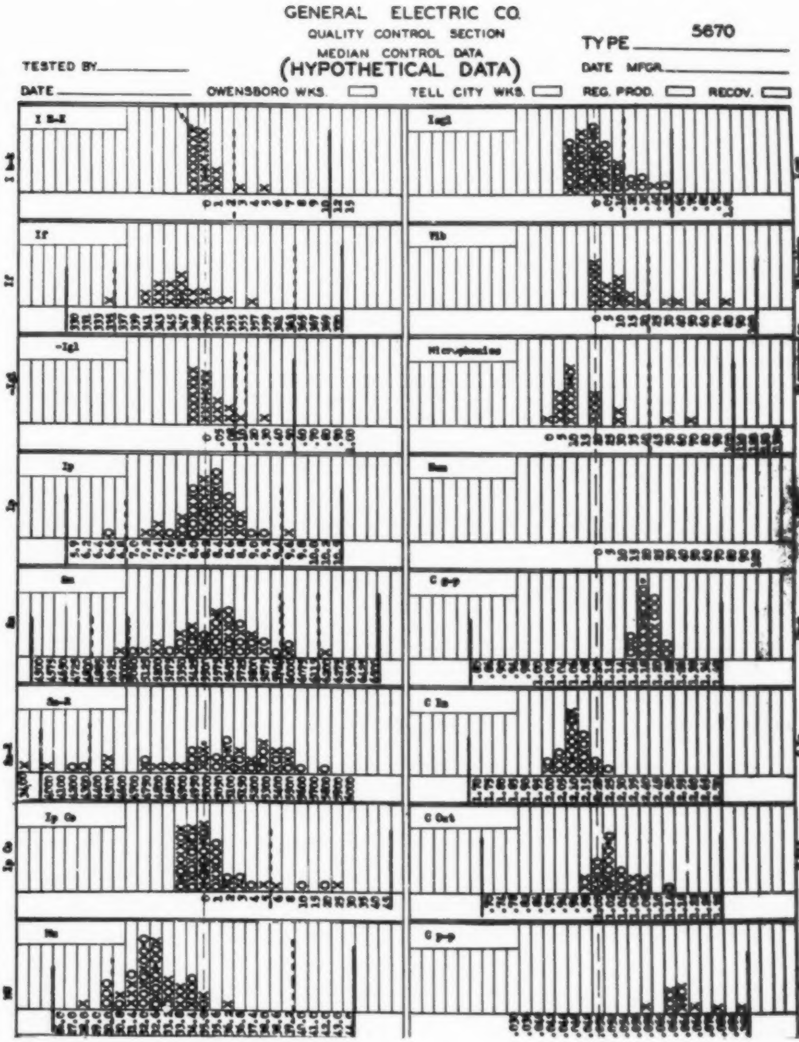


ILLUSTRATION 7

chart with a large red dot. If the median for the combined samples is within the reject limits the lot is acceptable for that test item. If the median for the combined samples falls outside either reject limit, the lot is rejected for that non-conforming test item. This procedure is followed for all electrical test items for which reject limits are shown.

A rejected lot must be reworked and/or retested 100% before resubmission for the median control sampling test. If only retesting is required, the resubmitted lot is subjected to the median control test for the non-conforming item(s) only. It should be noted that if the product is considerably off-centered, it will be necessary to test to limits tighter than the specified customer minimum or maximum in order to move the median within reject limits for acceptance on electrical centering.

Reference to Illustration 8 shows the operating characteristic curves for the Sm median in terms of per cent deviation of the product center from bogie. The normal reject limits which are set at ± 11.2% from bogie are used as long as the process center (average of last 10 medians) remains within ± 8% of bogie, the location of stricter reject limits for the median. The stricter reject limits are set up to permit a production shift (± 8%) only; whereas the normal reject limits are established to include this same amount of production shift plus sampling variation (± 3.2%). The same reject limit is used for both sample sizes $n = 20$ and $n = 50$, giving approximately 2 sigma and 3 sigma assurance respectively for acceptance of a product centered at the maximum product shift. For example, the sampling variation of the median is expressed in terms of bogie (for $\sigma = 6\%$) as follows:

Sample size $n = 20$, $2\sigma_M = 2(1.214)(6\%)/\sqrt{20} = 3.26\%$ of bogie;
Sample size $n = 50$, $3\sigma_M = 3(1.253)(6\%)/\sqrt{50} = 3.19\%$ of bogie.

The stricter reject limits merely displace the operating characteristic curve 3.2% toward bogie and by so doing force the product center closer to the specified value whenever it deviates more than the allowable amount of shift from bogie.

When the lot has been accepted for electrical centering, the life test sample of 20 tubes is started by the Rating Laboratory and the lot itself is sent on for acceptance testing by attributes.

The Product Acceptance Section takes a sample at random from the entire production lot and tests for inoperatives to a 3/4% AQL. The tubes are preheated and tested for shorted and open elements by tapping 3 times on the glass bulb in each of 2 planes 90° apart. Indicating neon lamps are used to determine the presence of shorts or opens. A tube is considered a reject if the neon lamps light improperly or show a flickering at any one or more taps. The tube is tested for high gas content in another circuit.

Illustration 9 shows the typical operating characteristic and average outgoing quality curves for the inoperatives test for a lot size of 500 to 799 tubes. This is a double sampling plan which uses normal or stricter inspection, depending on the process average. For example, the operating characteristic curves show approximately 93% acceptance at the AQL of 3/4% for normal and 81% for stricter

OPERATING CHARACTERISTIC CURVES FOR S_M MEDIAN

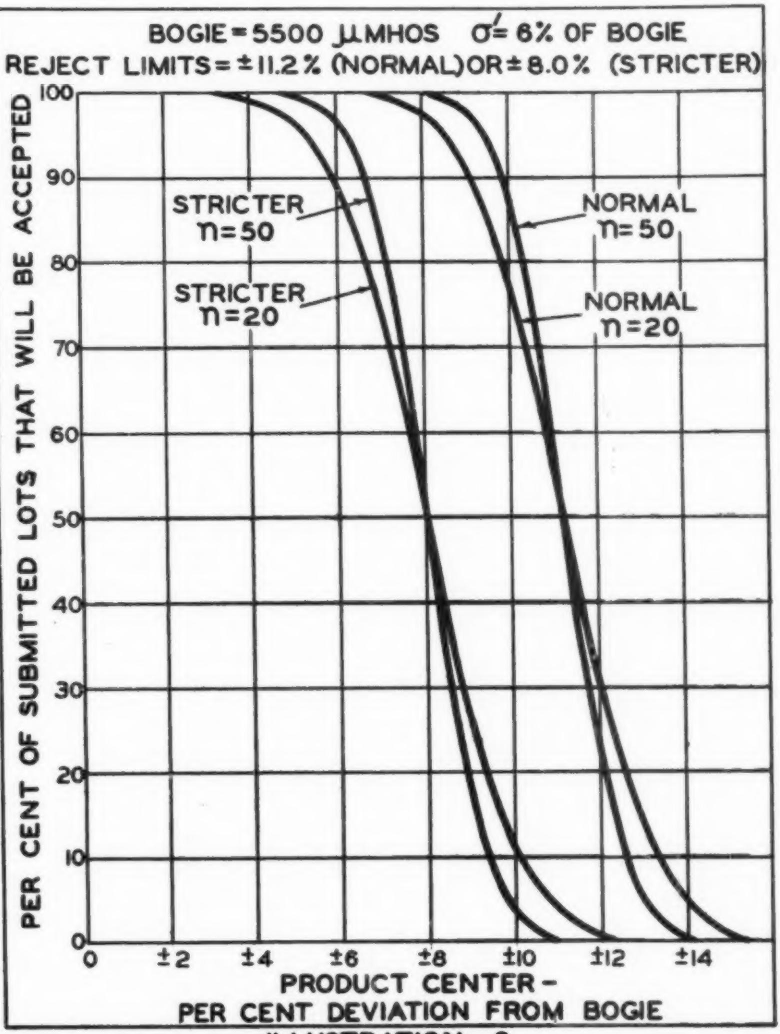


ILLUSTRATION 8

DOUBLE SAMPLING PLAN
FOR INOPERATIVES
3/4 % AQL

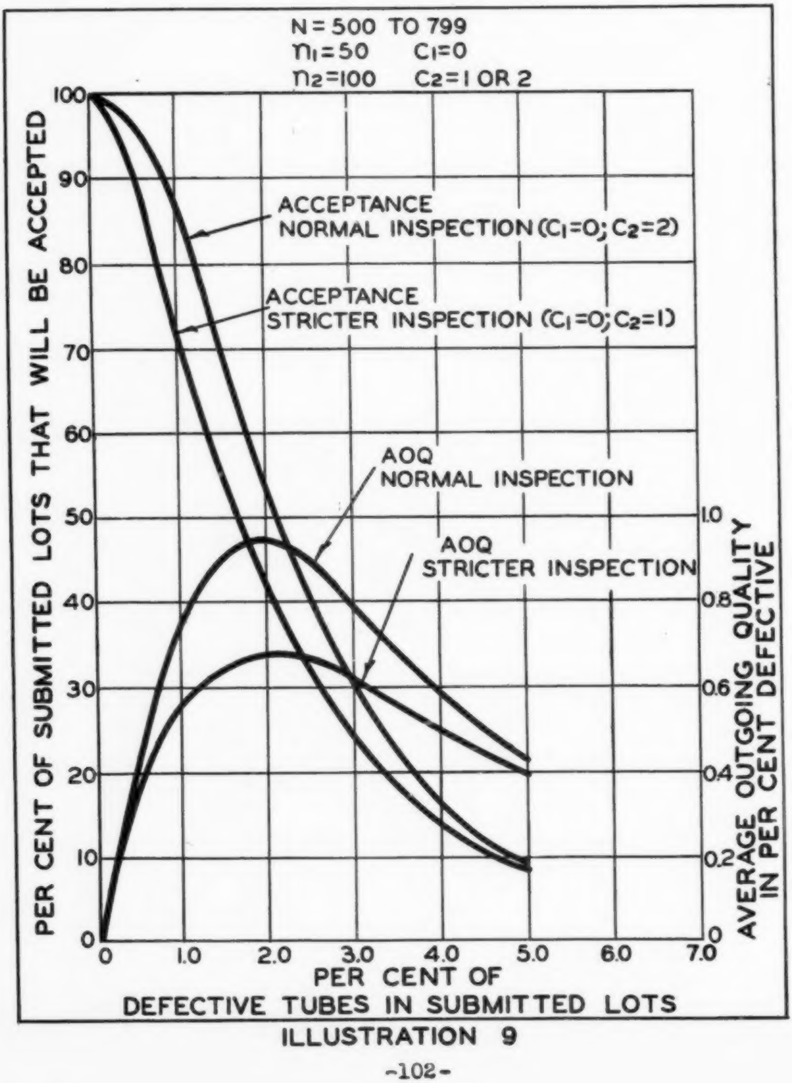


ILLUSTRATION 9

inspection. When the type disqualifies for normal inspection, it must be improved to the point where the average outgoing quality is not more than 0.4% in order to requalify for normal inspection. Continuation of the stricter plan until the product requalifies for normal inspection further insures the customer of good quality while the defect is being corrected in the product. However, for practical operation of the sampling plan for inoperatives economically the incoming production must not exceed 0.2 to 0.3%.

During 500 hour intermittent life test the tubes are cycled as follows: on 1 3/4 hours, and off 1/4 hour. This is a test to include both the inoperatives and electrical types of defects. Since these defects are of "sudden death" and "gradual incline" nature respectively, the life test rating is expressed in per cent of possible tube life attained by the sample in 500 hours. To be acceptable the life test sample must attain a rating of 95% at 500 hours.

These life tests are run at maximum dissipation which is considerably more severe than actual operation of the tubes in airborne equipment. Consequently our results of failing tubes on life test must be correlated with the per cent of failures experienced in actual operation. These failures on an accumulative basis describe a definite curve for each type of defect. The inoperative types are usually of the infant mortality nature, having their failure rate highest during the first 100 hours. The curve for electrical defects starts much later in the life period and appears to describe the tail end of a normal distribution curve. The composite of these two curves is the basis on which the tube life is judged. In order that samples be accepted regularly at the 95% tube life criteria it is necessary that the product show an average rating of approximately 99%. Assuming that the composite life curve of cumulative failures is approximately linear up to 500 hours, the per cent of tube failures is directly related to the rating as follows: $p\ (\%) = 2(100 - \text{production rating})$. This means that the product must average not more than 2% failures in 500 hours on life test and the corresponding failure rate in actual operation is estimated at 1.2%.

Communication of Results

Summaries of the essential data from the previous tests are made and circulated periodically to management, engineering and manufacturing. Thus the quality of the entire program for ARINC tubes is constantly brought to the attention of the responsible personnel. Any interim changes of life test ratings which affect shipments are immediately forwarded to the Shipping Section.

Summary

In closing we would like to summarize the following:

1. The quality control program extends throughout all phases of the ARINC program;
2. The quality acceptance methods have been set up to evaluate electrical centering, inoperative types of defects, and tube life;
3. Quality results at our plant are correlated with the results found from actual operation in aircraft equipment.

The program is a continuing one in which we are constantly striving to improve the reliability of our tubes in service. As improvements are made in the product, methods will be devised to evaluate the improved reliability. Hence, our present program can be thought of as merely a snap shot of what we are doing to assure our customers of high-reliability tubes at the present time. To date the results have been quite encouraging in that airlines' reports show a reduction of 5% to 50% in failures of equipment due to electronic tubes. We expect to further increase the high reliability of these tubes by means of quality control.

DEALING WITH LARGE AND SMALL SUPPLIERS

John T. Clark
Sentinel Radio Corporation

The man faced with the responsibility of accepting lots or groups of material for later use in producing a salable product has, in the last few years, gained knowledge of and practise in several new methods. These methods have given to his long established practise of inspecting only small samples from large lots the authority that comes from exact statistical knowledge. The application of these methods is by now very widespread, and the gains that have been made, as a result, in lowered inspection costs and improved relations between vendor and consumer are a matter of record for all to see. And those of us who have helped, each in our own way, to bring this all about may well take pride in the accomplishment.

But, statistical quality control is still only a means to an end, and its right and proper application must be made within the framework of thorough engineering knowledge of the process or product that we wish to control. In the case of acceptance inspection, it is vitally necessary that statistical sampling methods be used with due regard to the <u>source</u> of the product as well as the product itself. Since this implies a degree of familiarity with the manufacturer who produced the material you are to inspect, I should like to discuss with you some differences between producers at the extreme ends of the scale of bigness, and having done that, to point out how those differences may affect you as a consumer.

In all dealings with those manufacturing companies who supply the parts or materials from which your end product is made, it is necessary to bear in mind the very real differences in what we might call the "manufacturing approach" between those who produce their product in large quantities and those who produce a similar product in relatively small quantities. I should like to outline a few of these differences in order to show how they may affect the materials you receive.

To begin with, the large manufacturer is very likely to be supplying the same material or product to many users other than you, and since it is unlikely that all of you will be requiring shipment at nearly the same time, he will have a line, or a production group working on this product for long periods of time. The small supplier, on the other hand, will perforce have to split up his manufacturing activities into smaller runs interspersed with other, perhaps much different products. It is quite an obvious conclusion that all other factors being equal, the large organization is more likely to attain a state of good control over his manufacturing processes. Aside from the many elements of production continuity and stability that are implicit in long term or continuous production, and result in better quality, there is also the possibility that you, the consumer, will receive your materials in relatively large lots which have a very good chance of originating in a constant system of chance causes. This gives you who are charged with the responsibility for accepting this material a better than average opportunity to take full advantage of sampling plans to lighten the work of your incoming inspection department. The smaller supplier, producing his product in smaller lots, with his start-and- stop production, will force you to take more samples, oftener, in order to attain the same degree of acceptance protection over a considerable period of time.

Another contrast between the small and large producer is the difference in degree of inherent control over his product that the two must naturally exhibit. The large company will have its departments organized by function, and will have definite groups of people charged with inspection and quality control activities. These groups will have available what equipment and machines are necessary in order to be as certain as possible that all material produced is as it should be. The actual work done by the inspection staff will very likely be very carefully organized and perhaps done in accordance with written instructions from beginning to end. Within this framework, and without making allowance for the fallibility of men or machines, there is little chance that you will receive a large lot of unacceptable material. The small producer will put a great deal of reliance on worker quality, and will lean heavily on the ability of his production groups to control their own quality. Where he does make use of an inspector, there is likely to be a great deal of emphasis on "making sure the stuff is right" and an equal lack of actual direction to the inspector as to how he is to accomplish this. Under these circumstances, the chance that you will receive a lot of unacceptable material is much greater, of course.

The differences so far pointed out are of course commonplace and a very good case could be made in favor of either side as far as supplying a certain percentage of acceptable material over a long period of time. For while the small supplier is more likely to get into trouble, he will at the same time be able to get out of trouble more quickly, since his producing group is much more flexible, and he does not have so large an amount of material in process. When the large producer gets in trouble, he may have to shut down machines that require long set-up times, and all in all lose larger quantities of both time and material before he is under control again.

This all leads directly to another set of differences that also have a direct bearing on you as a consumer. In the case of the small supplier, the complete process of production, from raw material to finished product, is likely to be, if not directly, then at least very closely, under the control of one person who therefore has a perfect opportunity to take full advantage of his overall view and make the fullest use of what he knows of his business. He can purchase material which deviates from standard knowing precisely how he will alter his production process to allow for it, and his production department will have the fullest advantage of his engineering knowledge in planning its processes and procedures. When an emergency arises, the functions of quality control, engineering, purchasing and production are all brought to bear simultaneously, and with no personal frictions, on the problem. The boss, in his role as production superintendent, can tell himself as design engineer that the design must be changed before it will run in production, and lo, the design changes are made forthwith! Did you ever try this in a company where the chain of authority may extend up and then down again until perhaps a dozen separate persons must be brought into agreement before a standard may be changed? There is of course the probability that in a large company there will be less need for changes due to more thorough and adequate engineering.

To translate this so far verbal see-saw into more direct form, I should like for a moment to take the side of the large supplier and point out how, in our experience, he attains an advantage over the smaller producer. To begin with, to be large, a company is rather likely to be old, and to include in its personnel men who are acquainted in detail with the particular product you are interested in. For a precise example, let us examine

the sheet metal trades, who supply us with the various brackets, shields, chassis bases etc. that we use in such large numbers in the electronics industry. A company which wishes to specialize in these parts must have within its organization persons who are thoroughly familiar with manufacturing standards in this field.

Specifications for parts of this nature are decidedly vague when it comes to details such as how much of a burr is tolerable around a punched hole, or how sharp a bend is sharp enough when the drawing says "sharp corner". Acceptance standards are of course likely to be equally vague, but are still in the end based on what degree of goodness or sharpness or whatever is necessary in order that the part be usable. The supplier who, through long and varied experience, has learned what is acceptable practise and what is not is in a position to manufacture your parts in a fashion that will provide you with usable material, and with a minimum expenditure of raw material and manufacturing effort. He will know that such and such a job must be made with a progressive die in order to hold variations to an allowable figure, and equally important he will know that this other bracket or piece can be made satisfactorally with a two step process and save you much expense. And when you ask him to supply parts made of sheet metal by bending and forming with tolerances that cannot be met in this fashion, he will know that too, and instead of trying to supply something he cannot make, he will insist that you change your specifications.

Such very wide and varied knowledge of a product which, while only a bent, formed or punched piece of metal, still must be suitable for use with vacuum tubes and their associated parts, will not often be found in a small supplier. Equally, the small manufacturer of many other parts is at a disadvantage.

The manufacturer of small electrical parts such as condensers, resistors and similar things has a problem peculiarly his own in the amount of testing and measuring equipment necessary in order to be certain of the quality of his product. A small enterprise would have an impossible financial burden if they were to equip themselves to measure and control every possible characteristic of their product. Let us take the field of paper condensers for an example. The small manufacturer of paper condensers might maintain apparatus for the use of his production inspection department that would measure insulation resistance and test condensers for breakdown and measure capacity to some reasonable degree of accuracy. Beyond these characteristics he will likely be in complete darkness as to the quality of the product he sells you, and will depend on you to tell him when he is going astray.

For in addition to these characteristics, you as a consumer of condensers would want to know what degree of derating you must apply for operation at some elevated temperature. You would want to know how much the insulation resistance would deteriorate under exposure of humidity, how the reactance of the units varied with frequency, what degree of vibration they would stand when supported by their own leads, and perhaps even the temperature coefficient of capacity. The large manufacturer could tell you all these things in advance, and if necessary could furnish you with certified copies of his test run results. The small manufacturer could only say that he makes good condensers, he takes great precautions, but you will have to measure them if you want to know.

This gives a very direct illustration of what faces you in accepting material from both small and large suppliers of condensers. To make my

point clear; if you life-test a small sample of each sizable lot of condensers your attitude toward the test is widely different in the two cases. For the case of large supplier, your life test is a duplication, in the interest of verification, of tests he has already made. In the case of the small supplier, you are perhaps adventuring in uncharted waters. And if your samples fail their test, you may have to find out for him what it is that is wrong.

Perhaps this all sounds, so far, as though we should all purchase everything from a single group of gargantuan suppliers and let the rest of the world go hang. This is of course not the case, and here I would like to present the case for the small supplier. First and foremost, of course, he is flexible, and if you yourself are a small consumer, you and he will make an excellent team. His scheduling can be varied to adapt his shipments to your needs, resulting in savings in storage and inventory. Variations in his product to fit it to your needs can more readily be made, at less cost, and with less interruption to the flow of material to you. Due to his smaller overhead expense, the small supplier can give you more in the form of raw material for the same price, or the same product for a smaller price. He can perhaps do hand work on his product, due to his less-mechanized production processes, and thus adapt it to your uses when otherwise you would have to procure an item as a special at increased cost.

He can also, due to the much closer liason between his engineering and production departments, undertake work of a semi-experimental or unstandardized character which would be difficult to handle within the framework of a large organization.

This all points to the greatest field of activity of the small producer; that of the manufacture of specialty items. There are inevitably a few items in almost every complex product that do not fall within the framework of the large producer, who, due to his large scale operations, endeavors always to standardize his product in so far as it is possible for him to do so. These items fall naturally into the capabilities of the small manufacturer, and if you can see to it that he has full information and specifications as to what you desire so that his possible lack of thorough understanding of trade standards will not prejudice your material, then you will both benefit.

Now, how does all this affect you, as the consumer of the supplier's product or as the one responsible for accepting that product? As a beginning, let us consider the situation that arises when you have inspected a lot of material and determined that it must be either returned to the supplier or at any rate be reworked or inspected in detail to remove the defectives. When dealing with a large company, you will almost certainly find it necessary to work through the manufacturers representative or sales engineer for your territory. In order that your wants to attended to with cooperation and dispatch, you must enlist his cooperation. This you may do with little trouble if your records are accurate and well kept, and if you will make a practise of being as sure as possible of your position before calling him in. Once he is appraised of your difficulty and provided with figures or samples or both to bolster your claim, there yet remains the period during which he contacts the factory itself and endeavors to correct the trouble or achieve a disposition of the material. If what you have experienced is a sudden change in the level of quality, it may continue through subsequent lots for a period of time until the information has finally percolated down to the level where the product itself is corrected. Only experience will tell you

whether disposition of material yet to received should be a topic for discussion the first time.

To contrast the small supplier with this situation, your initial contact will probably be with either their salesmen, who probably doubles as an engineer or planning man, or with the production head. In any case you will deal with one who is not only in a position to understand your difficulty but who is also able to do something about it forthwith. You must be prepared, however, to lend aid and assistance in determining the true cause of the difficulty if it has its roots in an obscure characteristic that the supplier is not in a technical position to assess or investigate. Many small suppliers have lost profitable accounts, and many consumers have lost valuable and loyal sources of supply through failure to realize this.

I believe that what I am asking for in this whole discussion is better cooperation between vendor and consumer based on mutual understanding. And you as the consumer are in a position to do the most to foster this desirable end. The small supplier is dependent on you for not only the information contrained in what you reject, but for aid and assistance in those fields relating to his product which he has neither the talent nor the equipment to investigate and apply to his product. Both he and the large supplier have the right to expect that you will accept or reject their material on the basis of well conceived sampling plans that are correctly applied and supplemented by adequate records. If you will fulfill your part of this program, I am certain that your suppliers, be they large or small, will gladly fulfill theirs.

FINDING THE FACTS BEFORE SETTING THE SPECIFICATION

Julian H. Toulouse
Owens-Illinois Glass Company

Awakening interest in the setting of specifications by statistical backgrounds can develop a lot of "growing pains". While the ultimate goal will bring a greater understanding between the parties concerned with the specifications, there are sometimes some individual headaches in the beginning, particularly on the part of those who have not become fully aware of the statistical implications, but desire to use some means at arriving at definite specifications because, very largely, they have heard that others are doing so.

Some of these individuals apparently still harbor the thought that the way to begin negotiating a specification is to divide by two the suggestions that come from the other party in the agreement. An amusing instance occurred in our own experience only recently where a customer interested in setting a specification used this time-honored principle. It so happened that a range of measurement for an item was divided into five zones. This customer mistakenly thought that they indicated grades within tolerances, and therefore specified that they would not accept a grade greater than "number 2-1/2". This requirement was at the same time both amusing as to method, difficult to handle, and patent in its background.

Specifications may be desired solely for company use, for a producing industry, or between the industry and its customers. The problem of the setting of a specification may be difficult in a single company, as between engineering and production, but it is not insurmountable because at least there can be one man in the company who can resolve the differences by issuing a directive.

The problem is much more difficult between companies in an industry or between a buyer and a seller, and still more so between all the buying and selling elements of an industry. Two of the most far reaching organizations for such agreements are the American Standards Association, in which largely the great engineering and technical societies have memberships and the American Society for Testing Materials, in which consumer, producer and general interest representatives agree on general testing procedures although not necessarily on specifications. A.S.T.M. has an active committee, E-11, on quality control and statistical matters, which is concerned also with the several specifications on statistical sampling adopted by other committees. One of these for example, is C-224, covering sampling of glass containers.

The first question that we must ask ourselves in connection with a specification can be answered by a definition written by Dr. John Gailliard of the American Standards Association. Although Dr. Gailliard's reference has to do with standards rather than specifications, the main part of the definition equally applies. The statement was as follows:

"A standard is a specification
intended to serve
during a length of time
as a temporary constant level
for coordinating the factors
necessary for obtaining a re-current objective."

The important part of this definition is in the words that are underlined, particularly the fact that the implication is that a specification should be reviewed at regular intervals, because no specification should be static, and because it is for the purpose of coordination, leading to a definite objective.

In a further quotation from Dr. Gailliard we could add the first of a number of points that he has developed about standards and standardization. This initial point is as follows:

"When considering the establishment of a standard, get a clear picture in your mind of the ultimate objective you wish to attain,
For what reason do you wish to set up a standard,
What is the performance or condition in which you are aiming,
How do you expect a standard to help you in achieving this?"

From this it is apparent that it is fundamental to find out the facts concerning a production or the scope of a series of measurements of quality before you can possibly set a specification that is workable. Not only does one have to research the production but also to research the limits of the need.

A production may be controllable well within the specification, according to the variable characteristics of the equipment on which the material is made, and thus be entirely compatable with the specification; or production may have too great a variability, in which instance either the specification will have to be changed to include the production, or the method of production will have to be changed in order to produce articles within the specification, or individual selection or inspection of the piece-parts must be made in order to eliminate out-of-specification units. In summarizing in this fashion we are merely echoing statements that have been repeated many times.

Since it is impossible to state a number of generalities that would cover situations of interest to all who might be concerned, this paper will confine itself to the discussion of several methods which were used in order to develop specifications, or in order to develop information about an item from which a specification might possibly be written.

The examples given will cover several fields. The first is fundamental in that it studies the test itself, in this case being a measurement type which is objective in nature. It was developed in order to answer the question as to how closely can one expect a certain sample size to reflect the population from which it is taken, comparing theory with practice. The second is more from the standpoint of acceptance sampling and is a study of the effect of sequential sampling on a specification, particularly on the choice of a specification

level that would be suitable. The third covers a method of transition from one specification to another which covered the same desired quality but in terms of a different measurement. The last is a means of studying a material that was more applicable for specification by the "C chart" principle and connected with it a discussion of a situation where the sampling was much below the minimum that should have been used.

CHOOSING A SAMPLE SIZE FOR A TEST OF SPECIFICATION

Much has been written, more elaborately and more completely than can be given in this presentation, on sample sizes. The sample size to be used with a specification test is as important as the measurement details. One of our problems has been that of determining how small a sample we should take for routine purposes, or for specialized purposes, and the method here outlined has been rather successful in our laboratory in which the units, quite often destroyed in the testing, were of low enough cost that mass testing for a study of a principle could be used.

For no good reason except that it was a nice large round number we have studied most of the test instruments we employ by setting up as a basis a sample of 1,000 units, produced consecutively from the same machine and from the same mold. We have taken each of these lots as a classical population and have tried to determine how a small sample would relate to the entire population of 1,000 in terms of accuracy.

Our usual procedure is to number the units as they are produced and keep record of the test results in the same order that they are produced. Following this we can put the units together in groups of 5, 10, 25, 50, 75, 100 consecutive tests and so on, to determine the actual and the theoretical variation of the averages thus obtained. For the very good reason that the minimum and maximum units of a population can only be in one or two sub-samples, we have not attempted to study the probability of a minimum or maximum unit being in a sample but this could be developed directly from the data. From this we have hoped to be able to choose the sample size that would give us sufficient information for making a decision, the object, in the interests of economy of operation, being to test no more than would give us an answer that would be within certain practical limits.

Table I gives the results of such a test. Column I gives the sample size of 5, 10, 25 units, etc., and the rest of the data covers all possible combinations of consecutive groups of 5, or of 10, or of 25, and the like. The theoretical limits of the averages were obtained by determining the standard deviation of the lot of 1,000 and usual formula involving the sample size. From Column II thus calculated the theoretical lowest and highest average values for each sample size could be calculated and from the practical or experimental side the actual lowest and highest values for each sample size could be obtained. Both theoretical and actual values could also, from our previous experience, be expressed as percents of the average of the whole population without much error and the last two columns give the theoretical and actual percent of the total spread about the average.

TABLE I

ACTUAL VS. THEORETICAL SPREADS OF AN AVERAGE VALUE ACCORDING TO SAMPLE SIZE

Population Sigma = 7.15 Average = 65.87

Sample Size units	Theory Limits units	Lowest averages Theory units	Lowest averages Actual units	Highest averages Theory units	Highest averages Actual units	Spread / 65.87 Theory %	Spread / 65.87 Actual %
5	9.59	56.3	56.2	75.5	75.0	29.1	28.5
10	6.78	59.1	59.0	72.6	74.0	20.5	22.8
25	4.29	61.6	61.2	70.2	69.8	13.0	13.0
50	3.03	62.8	63.0	68.9	68.6	9.3	8.5
75	2.48	63.4	63.4	68.4	68.2	7.6	7.3
100	2.14	63.7	63.8	68.0	68.0	6.5	6.4
150	1.75	64.2	65.0	67.7	67.0	5.3	3.0
200	1.52	64.4	65.1	67.4	66.4	4.6	2.0
500	0.96	64.9	65.5	66.8	66.3	2.9	1.2

From such a study, after a decision that a routine test of quality would give us a satisfactory answer if we knew that it was within 5% of the average of the entire production, we have chosen a sample size of fifty. If we need more certainty, such as the comparison of two groups which have very similar average values we go to a sample of 200 or even 500 depending upon the circumstances and the closeness with which we want to make the comparison. In other words, our choice of sample size depends on how badly we want greater accuracy, and how much it is worth to us.

One warning should be given in doing such a calculation. Unless the process is under control statistically, there can be serious errors in decisions made on the basis of the test. We therefore, also plot the values as a control chart and accept a group for the purpose of standardizing a test method <u>only</u> if it is reasonably in control throughout the production.

SEQUENTIAL SAMPLING

One of our desires not long ago was to develop a means of sampling on the theory of an audit, where an inspector could go into a producing organization (in our case one of our own plants) and make an audit of the quality of goods in the warehouse ready to ship. We thought it should be on a sequential plan in order to hold the amount of sampling and therefore the cost to a minimum. The details of development can be cited as a matter of preliminary fact finding.

Before setting out to choose a sequential plan we decided to "research" the conditions that actually existed. Inspectors were sent out to look at a large number of lots taken at random from production ready for shipment and in the warehouse. In doing so they covered 125 lots of bottles, looking at 1,000 bottles in each lot. They recorded the serial order of each defective unit in the lot. Typical results

are shown in Table II. As a result we had a mass of data to which any sequential sampling could be applied. In the meantime all of these lots were followed through to their ultimate use and it was determined that all of them were satisfactory to the trade and had given no trouble. Basically therefore, these lots were known to be acceptable in quality.

TABLE II

SERIAL ORDER OF NON-CONFORMING UNITS IN TYPICAL LOTS

Lot No.	1st Defect	2nd Defect	3rd Defect	4th Defect	5th Defect	6th Defect	7th Defect
	Serial order in the 1000 bottle series						
1	350						
2	60	111	122	180	230	331	337
3	40	552					
4	144	177	360	755			
5	480						
6	330	699					
7	308	480	676				
8	67	97	145	152	241		
9	103	161	162	179	324	672	690
10	243	362	443	660	821		

	8th Defect	9th Defect	10th Defect	11th Defect	12th Defect	13th Defect	14th Defect
2	357	461	517	528	545	750	811
9	695	790	876	916	982		

At the time this was done the recent publications on sequential sampling plans were not available. We did not know much about risks, or sampling numbers and wanted to try out various combinations to learn more about such plans before setting up a procedure. We therefore, calculated a large number of possible plans with various risks, and with various acceptable and non-acceptable quality levels, as called for in the sequential system. In order to learn more, the several plans were based on systematic changes of the parameters.

Each of the tentative sequential plans was studied in relation to the population of acceptable articles. We did not try to find the plan that would accept all of the groups we examined. Some of them were at quality levels which we did not like to see shipped, even though no record of complaint resulted. We also "manufactured" some data by combining two groups of acceptable quality in order to see how the plan would act on rejectable ware. In the end, since this was for our own purposes and because it was therefore necessary to have a plan which would operate inside limits which might be requested by one of our customers, and since our object was to estimate the situation rather than to detail production, we finally chose a plan which might term "rejectable" about 10% of the lots that we considered satisfactory.

As to quality levels as used in sequential sampling, we had no guides. We knew our "goal" in terms of the percentage of non-conforming units we tried to stay below, and our first trial calculations took that figure as the acceptable quality level. We set the un-acceptable level at twice that figure. These levels did not work well when applied to known satisfactory ware; almost 50% of the lots we examined were rejectable. By trial, we gradually increased these quality levels, keeping a constant ratio of two between P_1 and P_2. That is not an entirely good idea, but we didn't know better. In the end we found quality levels which nearly fitted the fact that the lots we examined were commercially satisfactory.

The same technique applied to risks. Just to see how they worked, in terms of acceptance and in average sample sizes we first tried setting the producers and consumers risks at all possible inter-combinations of 5, 10, 15, 20 and 25%, soon discarding the latter level. This gave us families of sampling plans numbering either 16 or 25 in a family, depending on the use of the 25% risk figure. Now we could study the effect of these plans, as a family, as to numbers of lots rejected or accepted and the average sample number, in each combination of risks, for a given P_1 and P_2. By changing the P_1 and P_2 values, a new family could be calculated, for comparison with the first family and so on.

It was somewhat tedious, and, while we didn't wear out the calculating machine in the process, the new one we had just purchased was nicely broken in at the end of the project. And we did learn a lot about sequential analysis.

Table III shows a comparison of average sample sizes for one of the conditions. With both risks at 5%, the average sample size was 351. When the producers risk was 20%, with a 5% consumers risk, the average sample size became 234, and with the risks reversed it was 210. It must be emphasized that these figures were with our test lot data only.

Other comparisons were on the number of lots accepted, in which we found in general, that with a constant producers risk, about the same lots were accepted regardless of consumers risks, but that with a constant consumers risk, the number of lots accepted decreased with increasing producers risks. Table IV shows this analysis. Table V compares the effect of low and high risks on the lots used as an example.

We now know that our P_1 and P_2 values were too close together - the most satisfactory plans were on the order of 15% risks. If P_1 had been lower, and P_2 higher the risk figures would have been less on the same OC curve giving at least a psychological improvement.

In doing so, therefore, we tried out on our own production the effect of the several sequential plans that were tentatively considered. We found that certain levels should be quite acceptable both to us as producers, and probably to our customers because they included only lots which had been found satisfactory in actual use. I have been told that some sequential plans, adopted without study of the conditions under which they would be used, have been disastrous. For this reason we can highly recommend the method that we have used, "in order to find the facts before setting the specification".

TABLE III

ANALYSIS OF SEQUENTIAL SAMPLING
RISKS VS. AVERAGE SAMPLE SIZE
FOR A TRIAL LEVEL OF P_1 AND P_2

Consumers Risks	Producers Risks 5%	10%	15%	20%
	Average Sample Size			
5%	351	345	268	234
10%	313	290	228	189
15%	232	206	197	170
20%	210	196	190	170

Note: The changes shown apply only to the sampling plans studied and the populations available for application to the plans.

TABLE IV

ANALYSIS OF SEQUENTIAL SAMPLING
FOR A TYPICAL P_1 AND P_2 LEVEL
a. NUMBER OF LOTS ACCEPTED

Consumers Risks	Producers Risks 5%	10%	15%	20%
	Number of lots accepted			
5%	93	90	88	76
10%	95	91	89	77
15%	95	91	89	77
20%	93	91	90	77

TABLE V

ANALYSIS OF SEQUENTIAL SAMPLING
FOR A TYPICAL P_1 AND P_2 VALUE
b. LEVELS OF ACCEPTANCE AND REJECTION

n	Both Risks 5% Lots Accept.	Both Risks 5% Lots Reject.	Both Risks 25% Lots Accept.	Both Risks 25% Lots Reject.
72				
144			50	39
216	38	24	20	3
288	10	2	6	4
360	*		1	
432	10			2
504	8	3		
576	4			
648	3	1		
720	4	1		
792	1	1		
864	7			
Total lots	92	32	77	48
Total units	35,712	7,784	13,608	5,448
Total defects	187	160	35	115
Average Sample	388	243	177	114
Ave. Defects per lot	2.03	7.5	.45	2.4
Percent defects	.52	3.1	.25	2.1

*Acceptance number did not change at this level.

Now that several publications of sequential plans are available, including Military Standard 105A, there is no need of the calculations we had made. The published plans, with a producers risk of 5% and a consumers risk of 10% are quite generally applicable. In this connection, we might point out one very commonly mistaken use of the word "correlation", we have encountered. Two factors in quality, a field vs. a laboratory finding, have been under study, for example, in our laboratory over a period of years, in an attempt to find a correlation between them. So far we have been unable to find a statistical correlation. One of our customers (not statistically informed), in an effort to set a specification for one of these qualities in terms of the other has stated that he had definite correlation. His correlation turns out to be an observation that when the shipment contained items of questionable quality "A", he found results "X" in his use of the item. Where this breaks down is that quality "B" or quality "C", etc., may have been more important as causes of result "X". Investigation showed that there was nothing to substantiate his use of the word correlation, and it might better have been used as the word "coincidence". Many things can happen coincidentally which are not correla-

tive and mistakes can easily be made if this factor is not definitely taken into account in setting a specification. In finding the facts before setting the specification one must be sure that the "facts" are actually facts about the item considered for the specification and not a mere coincidence or fancy. If the wind blew your hat off, you wouldn't feel it was necessary to buy a different brand of hat. You would question the size of fit, or whether it was correctly placed on your head or you would hold on to your hat in a high wind. Any of these could be a cause of the same effect.

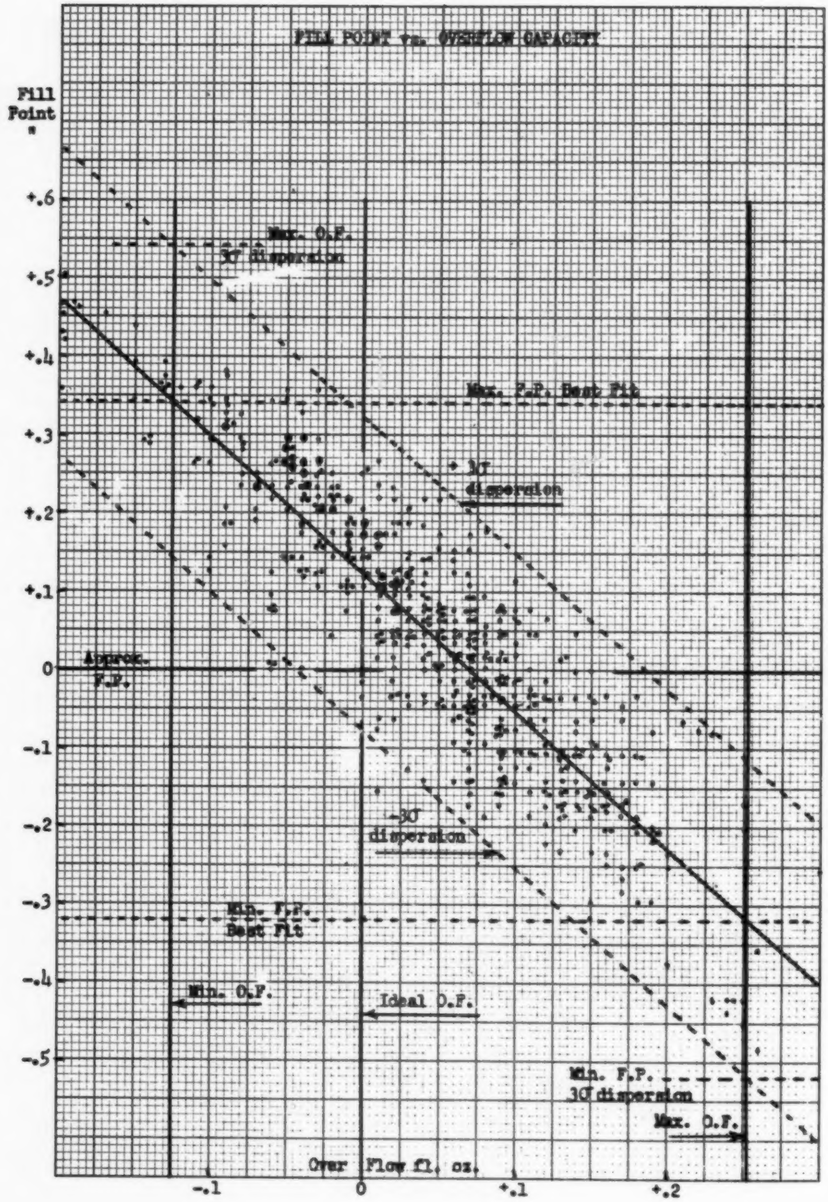
RE-WRITING A SPECIFICATION

In a recent instance, a proposal was made that specification for the capacity for a certain type of bottle, normally specified as the overflow or brim-full capacity be specified in the distance up the side of the container that would hold the content or rated capacity. The overflow capacity includes the sum of the rated capacity and the headspace or vacant space in the top of the bottle, an item which usually has certain specified characteristics, for expansion, pressure, and the like. The proposal stated a distance in inches up the bottle and tolerances in inches. The overflow capacity was in fluid ounces and was the established specification. The question was as to whether the proposed specification on a linear system of measurement was equivalent to the overflow or brim-full capacity in fluid ounces.

The new specification was suggested as an additional matter. It is almost an engineering maxim that there should not be two or more specifications covering the same requirement. In order to study this a number of different productions were obtained of the same item and both the distance up the side of the container that held the stated content and the brim-full capacity were determined on each of the items. A scatter diagram was drawn which co-related these data. The line of regression was then calculated and the point where this line crossed the specification lines was the close approximation of the linear distance measured on the side of the container that would contain the same quantity. We chose the regression on the established specification, although the two lines normally calculated were close together, and either could have been used. In this case there was no quarrel with the fluid ounce capacity specifications.

The accompanying chart showing how this was done very graphically shows that the proposed specifications would have excluded many units which were acceptable under the fluid ounce overflow specification and included units that were out of the present specification. This is the danger in having two specifications for the same thing.

To show the relative effects, the lines showing the minimum, ideal, and maximum limits of the present overflow, or brim-full specification arise vertically from the X axis. The intercept of the line of regression with each of these is shown by a full dotted line horizontally to the Y axis, or filling level measurement. Tentatively, these lines could be taken as the upper and lower tolerance limits which would give approximately equal rejection and acceptance.



FILL POINT vs. OVERFLOW CAPACITY
Fill Point
"
+.6
+.5
+.4
+.3
+.2
+.1
0
-.1
-.2
-.3
-.4
-.5
Max. O.F. 3σ dispersion
Max. F.P. Best Fit
+ 3σ dispersion
Approx. F.P.
-3σ dispersion
Min. F.P. Best Fit
Min. O.F.
Ideal O.F.
Min. F.P. 3σ dispersion
Max. O.F.
Over Flow fl. oz.
-.1
0
+.1
+.2

A new element enters here - the units found to be "within tolerance" are not always the same. Those units above and below the upper and lower full dotted lines, but within the vertical solid lines would be acceptable by the present specification, but rejectable by the proposed. Those within the upper and lower dotted lines, but outside the vertical solid lines would be acceptable by the proposed specification, and unacceptable by the present one. Combining the two specifications would increase the chance of finding non-conforming units. Changing the specifications would change the pattern of acceptability.

Only those units outside and inside both pairs of limits would be unaffected by the combination or the change.

This is shown simply as an example of how it is possible to translate the terms of one specification into the terms of another. This is quite important and while it is not strictly a matter of the statistics of probability, there can be applied a useful mathematical comparison. It is of course possible to calculate correlation constants and the like but from the graphical portrayal it is hardly necessary.

For those who might be interested, since these points were made up from different productions, they show the fact that different stages of mold life, and therefore, the actual size of the mold, result in a "travel" of the relative points on the scatter diagram along the line of regression from one tolerance limit to the other. Any one small group from a single production has a smaller variability than the total of the points shown in the chart, and this is shown by making those points on the graph that came from one single production larger than all of the others in order to indicate the relative spreads between a given lot, and lots which represent a mixture of mold lives. It is not a case of circular dispersion, but a matter similar to tool wear.

To further complicate the situation we have drawn the approximate 3-sigma limits on either side of the slanting line of regression and have drawn short dotted lines at the upper level of interception of the minimum overflow line, and at the lower level of interception with the maximum overflow line. Should tentative fill point tolerances be located at these levels?

QUALITY CONCERNING AN AREA

Since very little has been published regarding some of the area aspects in determining quality in sheets of material and the like, the fourth example concerns tests made on corrugated paper board in an effort to determine why the Mullen Test, which measures the bursting resistance of paper, was in poor repute because of its alleged undesirable variations. The fact that the specifications for the test were developed before the age of statistics in industry had considerable to do with the poor repute, because in the light of what we know now, the sample size is small and the consideration of variability is lacking. We were concerned in one of our tests because it was shown that the area involved, since these tests are made at various places on a sheet of the board, could also add to the known uncertainty of the test.

MULLEN VALUES: INDIVIDUAL

ONE TEST IN EACH SIX INCH SQUARE

245	240	227	253	260	223	265	246	230	241	225	190
220	228	244	240	233	215	246	255	225	185	205	200
215	240	233	239	220	232	252	257	240	240	245	220
267	235	200	230	260	200	211	233	240	205	233	194
240	220	213	250	205	255	233	238	228	220	190	202
230	209	228	217	240	212	275	229	194	232	219	215
235	208	245	233	239	225	189	220	210	190	183	200
245	230	220	235	246	226	226	193	206	240	200	215
216	255	225	200	233	200	260	239	235	235	205	205
255	260	251	237	265	248	220	228	260	220	215	190
250	245	219	237	260	236	235	250	231	224	215	252
245	230	260	240	202	255	220	220	233	212	221	220
260	253	215	232	239	239	242	200	253	201	218	192
238	233	233	255	240	245	233	248	258	227	200	215
232	228	235	252	263	253	244	260	217	212	210	205

MULLEN VALUES: AVERAGES OF NINE

FROM ONE TEST IN EACH SIX INCH SQUARE

	232	238	239	235	238	243	246	235	226	217	
	231	232	233	230	230	233	240	231	224	214	
	229	229	228	233	230	234	237	233	227	217	
	227	222	227	230	232	232	231	224	218	212	
	225	225	230	231	230	231	224	218	207	206	
	228	225	234	230	231	220	216	213	208	211	
	231	228	231	226	227	220	220	218	212	208	
	240	235	235	232	236	227	230	228	224	214	
	242	237	236	235	240	235	240	236	227	218	
	246	242	241	241	238	235	233	231	226	219	
	242	247	236	238	236	232	234	227	223	217	
	241	249	235	239	235	236	236	231	225	212	
	236	238	241	246	244	243	241	233	222	209	

Our example covers one sheet of corrugated board from a number of such sheets that were tested in the manner described below. The entire area of the sheet, 7-1/2 ft. long by 6 ft. wide was divided into 6 inch square sections and a Mullen Test was performed on each section. My second chart shows the individual values in the various sheets. The variation shown was practically meaningless.

We began to get order out of the jumbled mass of data by averaging the values in small areas. These areas were made to be overlapping. Our second chart gives the averages of these data, each average being placed in the center of nine squares, or nine values which made up the average.

For example, in the upper left hand appears the average, 232. It is made up of the value for that particular 6" by 6" area plus the eight similar areas that immediately surrounded it as a square 18" by 18". Below this is the value 231, and its position 1 square down in the area indicates that values for the 3 upper 6" by 6" squares going into the 232 average have been dropped and three new values in the next lower tier of 6" by 6" squares have been used instead.

Now we find something of interest in our measurement of quality. Very definitely the sheet of paper was divided into zones in respect to strength. Five quality levels of zones were chosen as shown by the key to the chart. The zones border on each other in logical fashion. In this instance it would be necessary to take a larger number of tests than now called for in the test specification applicable, and to make sure that all of the test areas were separated by sufficient distance that they could not by accident be in the same zone. If this is not done all of the tests might be in a weaker zone and give an equally false reading. Two laboratories or two testers might differ in their opinions solely because of the areas that they chose for the test and therefore in order to determine the facts before setting the specification it may be necessary to describe completely how the test for the specification should be made.

Many other examples could be given, but time does not permit. The fact remains that specifications should be set because of facts - facts from good statistical data. These facts should include both data on the material, and on its use. We are in a period of transition between specifications set by "concensus" or compromise of opinion and specifications based on the statistics of probability, both in production and use. There is no half-way ground. We must "find the facts before setting the specification".

TOLERANCE CORRECTIONS APPLIED TO PLASTICS FABRICATION

Edward B. Haden
The Esterbrook Pen Company

The case we wish to present today is by no means unusual. Similar cases have been recorded numerous times in many industrial plants. However, to those of you who are as yet not too familiar with the many techniques of Statistical Quality Control, we wish to show how effective an application of some of the more elementary tools can be. It has been said by several of the pioneers in Statistical Quality Control that when one approaches an operation, it is rarely found to be in a state of statistical control. That statement applies here very well. The corrections applied from the purely statistical sense would have been far from adequate. The combination of the analysis to follow and excellent cooperation from our engineering department provided the teamwork necessary to eliminate our troubles. The application of statistics in industrial plants can show the existence or non-existence of excess variations, and give some recommendations for remedial measures, but it must always rely on the engineering skills and manufacturing "know-how" for the actual corrections.

In the manufacture of our fountain pens we aim for the highest possible quality, and in addition to quality we stress the inter - changeability of parts. It is our philosophy to disturb our consumers as little as possible. If for any reason other than faulty manufacture, some part of a pen needs replacement, we want our pen owners to be able to buy the necessary part in his own locality rather than suffer the inconvenience of returning the pen to our factory for the necessary repairs. If we are to accomplish this, inter-changeability is a necessity. One such condition is the fitting of the sac - section to the fountain pen barrel. The sac - section is that part of the pen which holds the ink supply and the renew point. The barrel is that part which contains the pressure bar and the filling lever. These two parts are made from plastics materials. The section is manufactured from hard rubber and the barrel from cellulose nitrate. The latter is perhaps more commonly known as "pyralin" or celluloid.

Sac - Section and Barrel

Before the introduction of Statistical Quality Control in this problem the following conditions and procedures existed.

1. All barrels were gaged for I. D. on a 10% basis.
2. All sections were gaged for O. D. 100% and sorted into size categories.
3. At assembly, selective fitting was performed with allowances to fit 3 sections into each barrel. On the average 5% to 10% refitting was required.

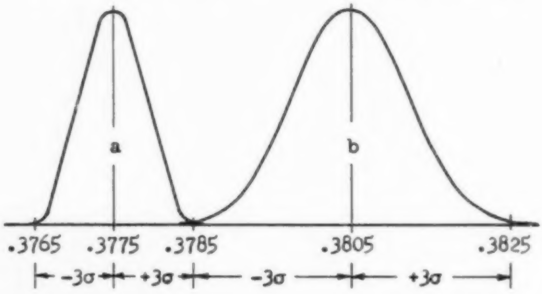
By contrast, the procedure of today is as follows:

1. All barrel I. D. sizes are controlled by $\overline{X}$ and R charts.
2. All section O. D. sizes are controlled by $\overline{X}$ and R charts plus scientific sampling.
3. At assembly, random fitting is performed with allowances for refitting once in every 100 assemblies.

A statistical analysis of these operations was conducted which revealed much information. Our engineering department had determined by actual test that for a proper fitting of the section to the barrel, the section tenon must be at least .0005" and not more than .0040" larger than the barrel bore. If the tenon was less than .0005" larger, the section would be too loose and would turn rather freely in the barrel. On the other hand if the tenon were more than .0040" larger, the section when fitted would bulge the barrel to the extent it was noticeable visibly as well as cause difficulty in fitting the caps to the barrels. Both of these operations are performed on automatic screw machines, and with the above conditions in mind as well as machine capabilities the following sizes and tolerances were established. These specifications were analyzed by fit curves as shown.

Engineering Specifications

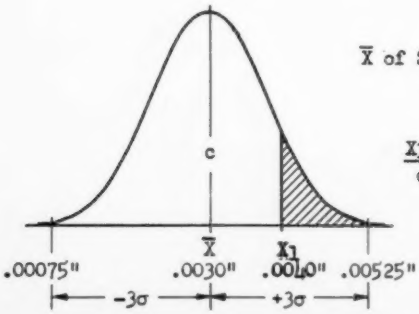
Barrel bore 0.3775" ± .0010"   Section tenon 0.3805" ± .0020"



$\sigma_a = .00033$ $\sigma_b = .00067$

$$\sigma_c = \sqrt{\sigma_a^2 + \sigma_b^2} = \sqrt{.00033^2 + .00067^2}$$

$$\sigma_c = \sqrt{.0000005578} = .00075"$$



$$\overline{X} \text{ of Section-barrel fits} = \overline{X}_c = \begin{array}{r} .3805 \\ \underline{.3775} \\ .0030" \end{array}$$

$$\frac{X_1 - \overline{X}}{\sigma_c} = \frac{.0040 - .0030}{.00075} = \frac{.0010}{.00075} = 1.33\sigma$$

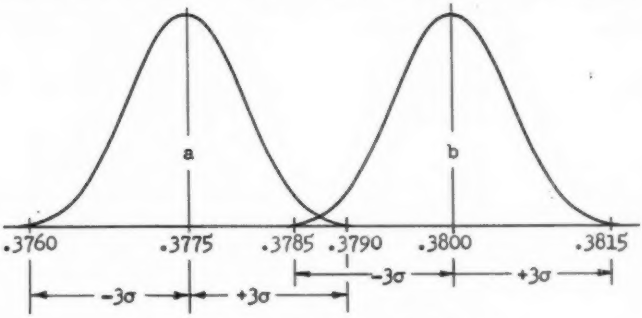
$1.33\sigma = 0.9082$

90.82% acceptable. [1]

The preceding solution shows that 90.82 % of all caps and barrels meeting the established tolerances would be satisfactory for assembly without selective fitting, that none of them would be loose and 9.18 % too tight. However, these results were not being obtained as it had been necessary to 100 % gage all sections and to selective fit the caps and barrels. In carrying the analysis further our first step was to check the desirability of the foregoing tolerances. Several sets of fit curves were developed and the following one accepted as the best from a manufacturing and economic viewpoint.

Quality Control Specifications

Barrel bore 0.3775" ± .0015"   Section tenon 0.3805" ± .0015"



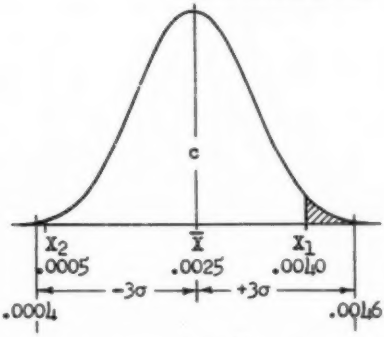
$$\sigma_a = .0005 \qquad \sigma_b = .0005$$

$$\sigma_c = \sqrt{\sigma_a^2 + \sigma_b^2} = \sqrt{.0005^2 + .0005^2}$$

$$\sigma_c = \sqrt{.00000050} = .0007''$$

$$\begin{array}{r} .3800 \\ .3775 \\ \hline \end{array}$$

$\bar{X}$ of Section-barrel fits = $\bar{X}_c$ = .0025"



X_1 = .0040"

X_2 = .0005"

$$\frac{X_1 - \bar{X}}{\sigma_c} = \frac{.0040 - .0025}{.0007} = \frac{.0015}{.0007} = 2.14\sigma \qquad \frac{X_2 - \bar{X}}{\sigma_c} = \frac{.0005 - .0025}{.0007} = -\frac{.0020}{.0007} = -2.86\sigma$$

$$\begin{array}{rl} 2.14\sigma = & 0.9838 \\ -2.86\sigma = & \underline{0.0021} \\ & 0.9817 = 98.17 = 98.2\% \text{ acceptable fits. [1]} \end{array}$$

A study in the polishing department showed that the section diameters were reduced by 0.0005" in that operation. It was necessary, therefore, to increase the $\bar{X}_c$ value from 0.0025" to 0.0030" and the proposed specifications became:

Barrel bore 0.3775" ± .0015" Section tenon 0.3805" ± .0015"

It is important to note the improved theoretical results from an apparently minor adjustment of the tolerances. By the application of statistical devices, in this case, the use of fit curves, we were able to increase the yield by chance fitting from 90.8% to 98.2% .

By theory we should have had 91.% good fits by chance on the original specifications, but we actually averaged 90-95 % which was accomplished by 100% gaging and sizing of sections. Machine capability studied showed the barrel machines to be of better accuracy than the section machines which partially accounted for the original tolerances of ± .0010 in one case and ± .0020 in the other. The section machines being the poorer, we centered our attentions at this point for the next analysis.

Common practice in adjusting cross slides on screw machines has been to do so with a small wedge and hammer. The following distributions were obtained by measuring pieces as they came off the machine and letting the operator adjust the tools as he felt was required. It should be borne in mind that at this time the gaging at the machine was performed with a go and no go ring gage. The gagings supplying the data were done on an air gage.

	I	II	III	IV	V
Over	xxxx	xxxxxxxxxxxxxxxxxx	x		
.0020	xxxxxx				
.0019	xxxx	x			
.0018	xxxx				
.0017	x		x		
.0016					
.0015	x			x	
.0014	x				
.0013			x	x	xx
.0012	x		x		xxx
.0011	xx		xxx	x	
.0010	xx		xx	xxxx	
.0009	x		xx	xxxxx	
.0008	xxx		xxx	xx	
.0007			xx	x	
.0006			x		
.0005	x	x	x		
.0004			xx		
.0003			x		
.0002					
.0001			xx		
.0000					
-.0001					
-.0002					
-.0003					
-.0004					
-.0005					
Under		xxxxxx			
Total	31	26	23	15	5

Σf = 100 sections gaged.

The scale given at the left of the frequency distributions is the scale on the air gage, the zero point being set by master plugs at .3805". This gage proved unsatisfactory due to its limited range of .0025", but it served for the time being in making the analysis. As can be seen there are 23 pieces too large to register on the gage, and 6 too small. The frequency distributions show that the operator was not able to adjust the machine properly and in his conscientious efforts was over - adjusting on a large scale. In order to properly evaluate the capacity of the machines, more frequency distributions were made, but in the cases to follow the screw machines were adjusted by sampling pieces with a micrometer and when the minimum point of the tolerance was secured, the machine was allowed to run for 100 pieces with no adjustments and the following picture obtained.

		f	d_1	fd_1	fd_1^2
.0010	x	1	-4	- 4	16
.0009	xxxxxxxx	8	-3	-24	72
.0008	xxxxxxx	7	-2	-14	28
.0007	xxxxxxxxxx	10	-1	-10	10
.0006	xxxxxxxxxxxxxxxxxxxx	20	0	0	0
.0005	xxxxxxxxxxxxxxxx	16	1	16	16
.0004	xxxxxxxxxxxxxxxxxx	18	2	36	72
.0003	xxxxxxxxxx	10	3	30	90
.0002	xxxxx	5	4	20	80
.0001	xxx	3	5	15	75
.0000	xx	2	6	12	72
		Σf=100		Σfd_1=77	Σfd_1^2=531

$$\sigma = C\sqrt{\frac{531}{100} - \left(\frac{77}{100}\right)^2} = C\sqrt{5.31 - (.77)^2} = C\sqrt{5.31 - .59}$$

$$\sigma = .0001\sqrt{4.72} = .0001 \times 2.17 = .0002$$

$$\sigma = .0002", \quad 3\sigma = .0006", \quad \text{and} \pm 3\sigma = .0012"$$

The distribution obtained, for a sample of 100 pieces, was fairly normal and more important, showed greater accuracy than had been anticipated. For insurance a larger distribution was made to see if the low range could be maintained.

		f	d_1	fd_1	fd_1^2
.0012	x	1	8	8	64
.0011	xx	2	7	14	98
.0010	xxxxxx	6	6	36	216
.0009	xxxxxxxxxxxxxxx	15	5	75	375
.0008	xxxxxxxxxxxxx	13	4	52	208
.0007	xxxxxxxxxxxxxxx	15	3	45	135
.0006	xxxxxxxxxxxxxxxxxx	18	2	36	72
.0005	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	33	1	33	33
.0004	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	34	0	0	0
.0003	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	31	-1	-31	31
.0002	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	32	-2	-64	128
.0001	xxxxxxxxxxxxxxxx	16	-3	-48	144
.0000	xxxxxxxxxxxxxxxxx	17	-4	-68	272
-.0001	xxxxxxxxxxxxxxxxx	17	-5	-85	425
		Σf=250		Σfd_1= 3	Σfd_1^2=2201

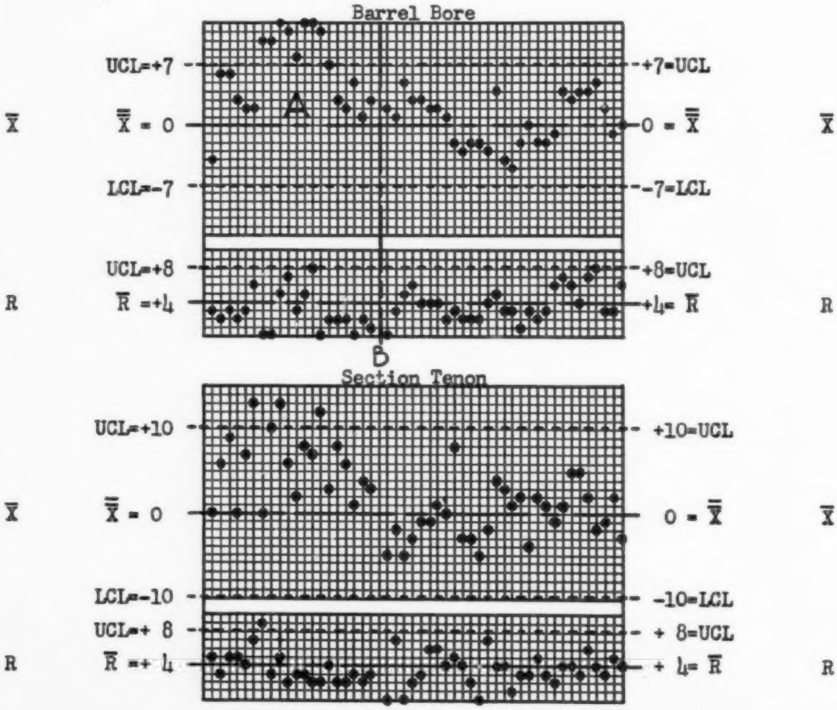
$$\sigma = C\sqrt{\frac{2201}{250} - \left(\frac{3}{250}\right)^2} = C\sqrt{8.804 - (.012)^2} = C\sqrt{8.804 - .0001}$$

$$\sigma = .0001\sqrt{8.8039} = .0001 \times 2.97 = .000297 = .0003$$

$$\sigma = .0003'', \qquad 3\sigma = .0009'', \quad \text{and} \quad \pm 3\sigma = .0018''$$

The distributions showed two things; first, the section machines were capable of producing parts well within the desired tolerances, and second, the operators were unable to adjust the machines with the desired accuracy. Although only one distribution of 250 pieces is shown, several were made and all gave results within ± .0010", ample evidence that the machine capabilities were satisfactory.

The solution of the machine setting and adjustment problem was more difficult. Micrometer adjustments were not available from the manufacturer of the machines nor were they interested in designing special ones for our equipment. Our engineering department designed and produced micrometer adjustment attachments for the machines. Air gages accurate to .0001" with sufficient range were obtained and placed at the machines. The combined effect of these enabled the operators to get the maximum efficiency from the operation. At the same time similar air gages were introduced on the barrel bore operation and $\overline{X}$ and R charts introduced to both types of machine. Samples of the charts obtained are shown below.



The $\bar{X}$ and R chart of the barrel boring operation (a) is particularly interesting. It is a good illustration of the need for the operator to understand and accept his position with relation to the quality of the articles being produced. The operator involved with the chart illustrated was resentful when the chart first appeared by his machine and control was not obtained as shown by the first part of the chart. Time was taken to educate this operator as to the value of the chart and what benefits were hoped for in assembly and dollar savings if control could be obtained. His resentment vanished and was replaced with enthusiasm. The chart from this point (b) on illustrates a marked improvement following the operator's acceptance of the control chart method.

We stated in the beginning of this paper, that on the section manufacture, scientific sampling was performed in addition to the $\bar{X}$ and R chart. The reasons for this were as follows: 1. A change in dimension of the sections did occur as a result of the polishing operation. 2. The savings accrued by the sampling from the previous 100% gaging were very gratifying and the cost of sampling so small it was felt inadvisable to remove this insurance of proper fitting at assembly. For those interested we use a modified Army Ordnance Sampling Table [2], which we have found to be most beneficial for our needs.

The ultimate result of this analysis and cooperation of engineering has been to produce the following:

1. Elimination of most 100% gagings.
2. Greater tool wear due to less adjustings and replacements.
3. Elimination of selective fitting at assembly.

On the basis of our present production schedules, the improvements made in these two operations are currently yielding an annual saving of approximately $ 4000.00 in direct labor alone, which is more than sufficient to warrant the effort expended to obtain these results. From the statistical viewpoint, the analysis and corrections were made possible by the use of frequency distributions, fit curves, control charts, and sampling tables; none of which require any extensive statistical background for their use. This is a typical case where anyone with a little knowledge of the fundamental techniques so easily obtained, can make substantial savings in dollars and accomplish major improvements in quality and uniformity of the product for which he is responsible.

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Bibliography.

[1] Statistical Quality Control, by Eugene L. Grant

[2] Modified Sampling Tables, Edward M. Schrock

THE ARMY'S PROGRAM FOR QUALITY CONTROL

Colonel C. E. Capito, GSC
Department of Defense, United States Army

I trust that when I get through this morning that you do not feel about my discussion the way the Indian felt about the traveling salesman during the pioneer days. It seems that this drummer was trying to impress the proprietor of a trading post at a time when the only other person in the store was an Indian. From time to time, when the drummer paused for breath, this Indian had just enough time for the statement, "my cow died." After awhile the Indian, rather grumpily, stalked out of the room, whereupon the drummer interrupted his patter and said, "What's the matter with that fellow? Is he stupid? All he said each time he opened his mouth was 'my cow died!'." The proprietor smilingly answered, "That man is far from stupid. What he was implying was he had no use for your bull."

I repeat, I trust that no one here needs to think or remark on dying cows during my talk this morning.

Before launching my discussion on the subject of the Army's inspection organization and its functions, I think it is in order that I brief you on the purpose of the organization and a little of its philosophy.

The Army inspection organization's prime concern and responsibility is quality. This statement will, I am sure, surprise no one. However, how many people understand the place in the production and supply system at which the Army's major quality interest is centered?

Your reaction to this quite probably is: "Quality is quality! I make shell and they are either good or bad. There is just one quality. That of the shell."

This comment, which I believe you would have made if given the chance, helps my point. The one and only quality responsibility that the Army is charged with is that of the material which reaches our using forces. Our prime concern, using the shell again, is not the quality of the shell coming from your load line or the metal parts plant, but is the total quality of the shell in the box opened in the field by the gun crew.

You might properly counter that I sound like I am splitting hairs and setting up a quality category that does not seem to be natural. Now that I have started this issue, let us dig a little deeper and see whether or not I have a point.

The producer of an item or component for the Army has a very deep concern for the quality of the material taken from the end of his process and submitted to the Army inspector for acceptance. He has design requirements and contract schedules to meet and must deliver according to these commitments in order to keep his plant functioning and meet his obligations. The Army inspection organization's responsibility strictly begins at this point inasmuch as we are not producers but "assurers." We assure the Field Commander that the material being issued to him can be used in the manner for which it was designed.

An often used, but improper, analogy would be that at this point the Army inspector functions as a screen. He allows the acceptable material to go through to the field and prevents the sub-standard from doing the same. Here is where I think we can substantiate the Army's philosophy of quality responsibility.

If the inspector should be allowed to function as a screen at the end of the production line, we believe that it would be a highly uneconomic situation, even if it were possible to accomplish. The size of the operational inspection organization necessary to accomplish a screening responsibility would necessarily be enormous. It is frankly just about impossible for the Army to develop such an organization. In order to even pretend to accomplish its charge, this organization would have to <u>thoroughly</u> and <u>completely</u> inspect the material presented for acceptance. It is common knowledge that discovery of defectiveness at the end of the production line is too late. In order to manufacture economically, a contractor must inspect and control his process throughout its operation. If we are to come in at the end and <u>thoroughly</u> and <u>completely</u> inspect an item it is obvious that the duplication of inspection and its attendant waste of manpower is in the neighborhood of one hundred percent. For the above salient reasons, and others just as obvious, the Army feels that the prime material quality responsibility is the contractor's and that our function is accomplished if, by controlled checking of the output of the process, which by the way includes contractor inspection, we are assured that the process is doing what it was designed to do.

If the Army's technique of Quality Control acceptance is viewed in the light of this discussion, many of the Army's actions regarding inspection and acceptance will appear more understandable. It cannot be too strongly emphasized that the Army will not, as a policy, screen out defective material offered for acceptance. We will inspect only to the degree necessary to assure that the contractor is doing the job we contracted with him to do.

In order to get a clearer understanding of the Army organization for the inspection of procured supplies, I have prepared a chart showing only the points of interest to us. (Slide 1) Heading up the Military Organization we have the Department of Defense with overall responsibility to so direct the separately administered Army, Navy, and Air Force along lines that will result in successful prosecution of military operations with the minimum of waste and confusion. Assisting the Secretary of Defense, there is the Munitions Board for the purpose of bringing together the technical know-how of the three Military Departments. Coordinating the information thus gathered and either advising the Secretary of Defense on problems or issuing as joint documents the policies of the three departments which have been developed and agreed on. The Department of the Army, one of the Departments directly under the Department of Defense has an Under Secretary whose prime responsibility is the development, procurement, and handling of supplies necessary for Army operations.

In direct control of these activities there is an Assistant Chief of Staff, G-4 (Logistics). The ACofS G-4 has an organization broken down to divisions that handle staff control and coordination of Research and Development, Supply, Service, and Procurement with the Inspection function being under the Procurement Branch. Actual operations in these fields are carried on by the Army's seven technical services. Each of these technical

services have established field offices with authority to handle procurement inspection problems.

The Ordnance Corps maintains fourteen (14) District Offices. (Chart 2) These field headquarters are located so as to most effectively deal with the problems arising on the items that Ordnance purchases.

The Quartermaster Corps, with its main Inspection Headquarters in New York City (Chart 3) has established other focal points for inspection activities in Chicago and Oakland.

The Signal Corps at the time this chart was prepared (Chart 4) had three field offices responsible for the United States. As delivery requirements increase the country will be divided into four sections (Chart 4A) with the West Coast being handled from a Los Angeles Office.

In arranging for the procurement and inspection of Chemical Corps supplies, it was found desirable to break the area of the United States into six (6) sections (Chart 5), each section being under the supervision of offices located in the cities shown on this chart.

The Chief of the Army Engineers, after thorough study of the problem, encountered in the procurement and inspection of engineer items of supply during World War II, has established a new area breakdown to more effectively handle future problems. (Chart 6)

The Surgeon General has divided his procurement and inspection responsibilities into two major categories; the first dealing with medicines and surgical supplies is purchased by a joint Army, Navy, and Air Force activity, ASMPA, in New York with inspection being handled by the Navy Inspection Service of the Office of Naval Material; the second, inspection of foods of animal origin being assigned to the Veterinary Corps. Arrangements have been in effect for sometime whereby the Department of Agriculture inspects a large amount of Army-purchased food of this sort. The remainder of the foods of animal origin are inspected by Army Veterinary personnel located at strategic points as indicated on this chart. (Chart 7) All procurement and inspection matters relating to Transportation Corps supplies are handled in the Marietta Transportation Corps Depot, Marietta, Penn.

As this brief review of Army field activities shows, a serious attempt has been made to decentralize the procurement and inspection functions to such an extent that each type of item will be the responsibility of an office close to the scene of manufacture. The very fact that this has been accomplished tends to foster, if we are not on constant guard, an appearance of duplication. Ever since the middle of World War II, the Army has had a firm policy to the effect that whenever an inspector finds another government activity represented in a plant he visits or where he is stationed, he is to advise his supervisor and a mutual attempt is to be made to arrange it so that one inspector handles all inspection in that plant. Under this policy, it can be seen (Chart 8) that the Army has available, in most every production zone of the country, an inspection organization capable of handling any problems that may be encountered. Several years ago a joint inspection committee under the Munitions Board, made up of members of the three Military Departments, recommended and received approval of a policy statement that widened the inspection interchange system to include all military activities. This statement is given in memorandum from the

Munitions Board to the Secretaries of the Army, Navy, and Air Force, dated 5 April 1950. A closer coordination of the inspection efforts of civilian government departments and the military is now a subject of study by the Government Services Administration in conjunction with the Military Departments.

With this background on Military Organization let us review for a minute the types of inspection required on the supplies purchased. There are three main types to be considered. This chart (Chart 10) shows them with a brief statement of the salient points of each. First, we have contracts for the Research and Development work on a new item. Government inspection of this type of contract consists, for the most part, of assuring that efficient methods are used, the correct materials are chosen, that, in general, military standards are complied with, and that the item finally developed satisfies the military requirements. The second type of inspection has to do with large complex items produced and purchased in very small quantities, sometimes only one unit of an item of this sort is needed. Inspection of this type of item consists of a general review to determine overall compliance with requirements, various tests to determine functional characteristics and detail inspection to assure that the features that affect interchangeability of components, and so forth, are correct. The third type of inspection concerns itself with standard items of supply that are mass produced. An item is adopted as standard when all interested military activities have agreed that it is best suited to fulfill military needs and when a representative cross section of industry has indicated that the item can be produced in accordance with the requirements. I would like to emphasize, at this time, that when proposed specifications are sent to your companies for comment, that a real service can be given to the country by conscientious review of the specification with clear unambiguous comments as to changes desirable to make the item more producible or that will effectively assist in more economical use of men and materials. The major interest of those attending this convention is, I believe, centered on quality control programs related to inspection of this type of item last mentioned.

Early in World War II the Army discovered that efficient procurement of quantities of supplies required to successfully carry on military operations could best be effected with the assistance of statistically sound acceptance sampling procedures. The correct balance between perfect material in limited quantities and the blind acceptance of supplies regardless of quality seems to lie in the region where lots or batches are considered acceptable in spite of the fact that a small fraction of the total is not in exact conformance with the specifications, standards, and drawings. It is customary for the Military Departments and for a large number of Industrial concerns to set limits on this fraction that does not conform to requirements in terms of "Acceptable Quality Levels" or "AQL's". Since the various defects that may be present in a particular item vary in importance, most items are reviewed and the possible defects are sorted into groups. This results in what is known as a "Classification of Defects." In accordance with Military Standard 105A the various groups into which possible defects are sorted are known as critical, major, and minor. Critical defects being those which entail danger to using or handling personnel and the AQL for such defects is either tight or as in many cases where the defect, if present, has extremely grave implications, one hundred percent inspection must be utilized. Major defects are those defects, other than critical, that could re-

sult in failure, or materially reduce the usability of the unit of product for its intended purpose, while minor defects are those which do not materially reduce the usability of the unit of product for its intended purpose, or is a departure from established standards having no significant bearing on the effective use or operation of the unit. Separate AQL's are established for each class of defects.

Many people, when first exposed to the idea of accepting items in batches or lots that are known to contain defective items, immediately jump to the conclusion that some of the accepted items are bound to fail when used. Actually, when the probability of an item being very far outside the limits is considered, especially under the reasonably tight AQL's established for most military items, it is understandable why few, if any, items procured with this type of inspection failed during World War II.

It is very important that each contractor, whose product is to be inspected and accepted with these sampling techniques, know in advance of a contract award exactly what Classification of Defects and AQL's are applicable to the items he is to supply. When it is realized that a change of only a few percent in an AQL may result in doubling or tripling the amount of one hundred percent inspection required on the part of a contractor, I believe that all contractors will demand such information in advance.

The Army has at present many specifications that include, in the inspection clauses, statements establishing the Classification of Defects and the Acceptable Quality Levels. In the future all specifications for items adopted by the Army as standard items of supply will contain such statements. With these statements established in the specifications, all contractors are thus assured that they are not subject to the whim of an individual but are being treated impartially as regards an important factor in their cost of producing for the Army and those contractors who are able to produce higher quality will find that they have an enviable position in the competitive bid system.

Of course, there will be a transition period during which many specifications, for items that will be inspected and accepted with standard sampling techniques, will not include the Acceptable Quality Levels and the Classification of Defects. Army policy regarding purchases of this sort is established in Section XIV of the Army Procurement Procedures with the following statement, which I quote, "The use of sampling inspection plans with their associated Acceptable Quality Levels and Classifications of Defects has an effect on the cost of producing and delivering supplies contracted for by the Government, therefore, all invitations for bids and subsequent contracts shall include or reference the applicable Acceptable Quality Levels and Classifications of Defects when they are to be used in the inspection of supplies being procured."

At this point in our discussion, I would like to compare the philosophy of the Army regarding inspection with the idea that many people have which, in effect, maintains that there is no need for actual inspection on the part of Government personnel. Of course, the people who feel this way base their thinking on the assumption that the contractor, in fulfilling his obligation,will maintain an inspection system that will insure nothing but high quality items being offered for acceptance. These people then point to the standard military contract which contains a clause to the effect

that the contractor must maintain an inspection system that is acceptable to the Government. The Army agrees wholeheartedly with the basic intent of this thinking but, feels that in actual fact the Government inspector should first, by direct inspection, ascertain that the assumption, a contractor delivering acceptable product, is valid. This does not impugn the character of the contractor but is rather the logical result of analyzing conditions as usually exist wherein a contractor is manufacturing and inspecting items foreign to his normal operation with, in many cases, personnel that have been hurriedly recruited.

Military Standard 105A, which will be discussed in detail this afternoon by Commander Lubelsky, has procedures built into it that automatically decrease or increase the inspection performed by Army inspectors so that when a contractor excels, quality wise, reduced samples are utilized in determining acceptability. Naturally, the acceptance criteria are revised to give greater protection when the quality offered to the inspector is significantly poorer than the Army requires. The ideal acceptance sampling plan would have an operating characteristic curve shaped as shown on this chart. (Chart 11) Everything that is equal to or better than the AQL would be accepted and every batch or lot that is poorer than required would be rejected. Chance variations due to sampling make this ideal situation an impossibility. However, when the composite reduced, normal, and increased protection plans are studied, an overall operating characteristic curve is revealed that is of this general shape. (Chart 12) As we see, the reduced inspection plans are designed to acceptpractically all product that is significantly better than required, the normal plans aportion the two risks, in favor of the contractor, that is, the Military takes a much greater risk of accepting poor lots than the contractor runs of having good lots rejected, and in the event the contractor slips and submits product definitely poorer than the Acceptable Quality Levels the increased protection plans result in most of it being rejected.

An interesting situation is created regarding gages and the validity of quality decisions made with their assistance because the allowances to take care ofwear and the necessary tool-makers tolerances have to be established in such a manner that the actual size of gages is always somewhat inside the component tolerance limits. Therefore, as is shown on this chart (Chart 13) gages usually steal part of the total variation allowed on the items. This situation had little meaning prior to formal acceptance sampling procedures but now, when a decision involving the possibility of requiring that sizeable quantities be one hundred percent inspected, may depend on the judging of the quality of a single item, it becomes vitally important that such judgment be very precise. Army policy regarding this situation is to the effect that a contractor has the right to request precision measurement when he feels that a decision to reject is possibly based on pieces erroneously found defective by a gage. Such a request does not have to be formal and in writing but should be preceded by a contractor check with precision techniques.

Before closing this presentation, I want to outline in general the various activities we have currently under way to first, improve the application of statistical techniques to quality control and quality assurance, and second, encourage wide spread use of what we believe is one of the greatest advances of our generation in the field of production and inspection.

First under improvement, we have a committee established under the

auspices of the Munitions Board Material Inspection Agency that is charged with the development and promulgation of standards in quality control and quality assurance. The recently published Military Standard 105A is one result of this committee's activities. Sometime this summer an instruction document on the use of this standard will be published. While on this, I would like to ask that any of you who have comments or suggestions that will help in the preparation of these instructions to send them to the Chairman of this Committee, Mr. Silas Williams, Jr., care of my office. Further studies are being made on theory for the assistance of this committee on such subjects as combination variables and attributes acceptance plans, continuous sampling plans that guarantee specified output qualities, etc. These studies are being carried on under Research and Development contracts with various universities, jointly financed by the Army, Navy, and Air Force and administered by the Office of Naval Research.

Secondly, in an attempt to further the use of these techniques the Military Departments have jointly developed a moving picture in two parts, the first part is on Process Control Chart techniques which will be shown after Captain Williams' discussion and the second part is on Acceptance Sampling which will be shown this afternoon after Commander Lubelsky finishes his presentation on Military Standard 105A. It is also contemplated that the techniques developed by the Military in this field will be published in the form of standards that are to be sold by the Government Printing Office for nominal sums.

In conclusion, I want to say it is a pleasure for me, as an Army representative, to be here this morning. We believe that the work you gentlemen are doing in the American Society for Quality Control is of the utmost importance in aiding the Armed Service Procurement Program.

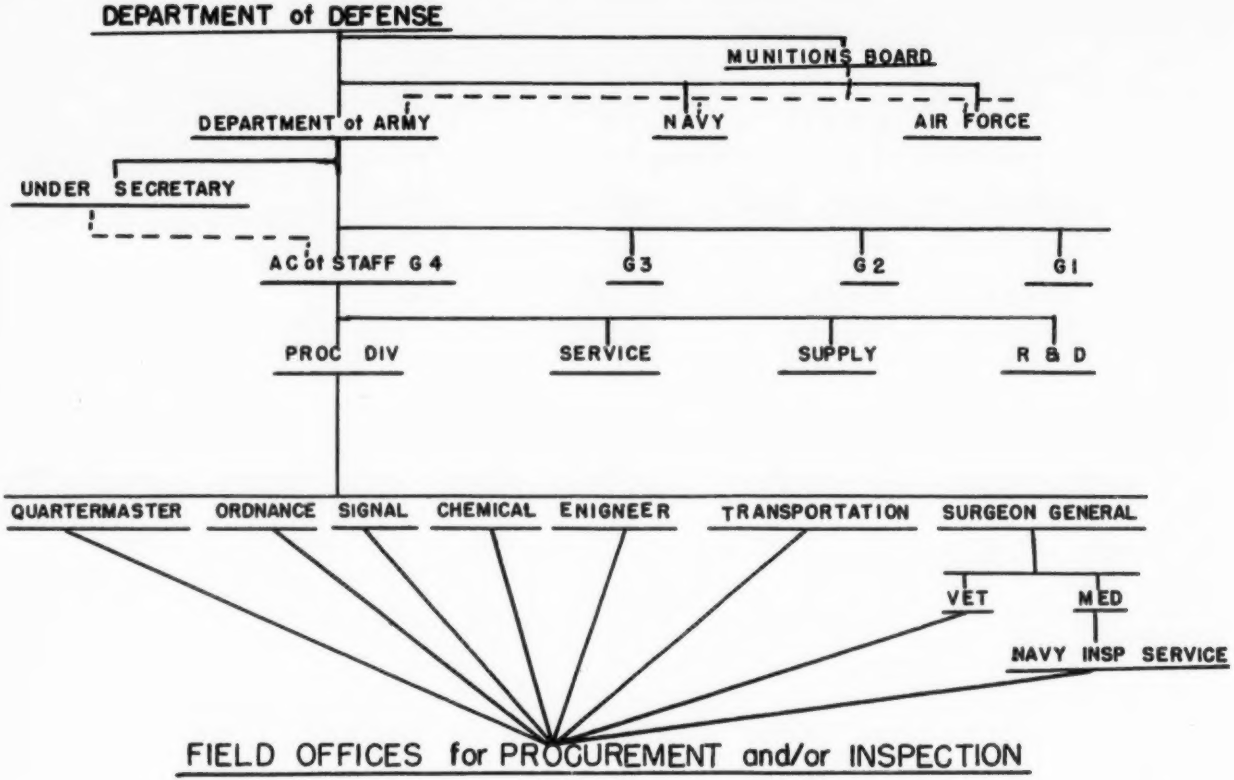
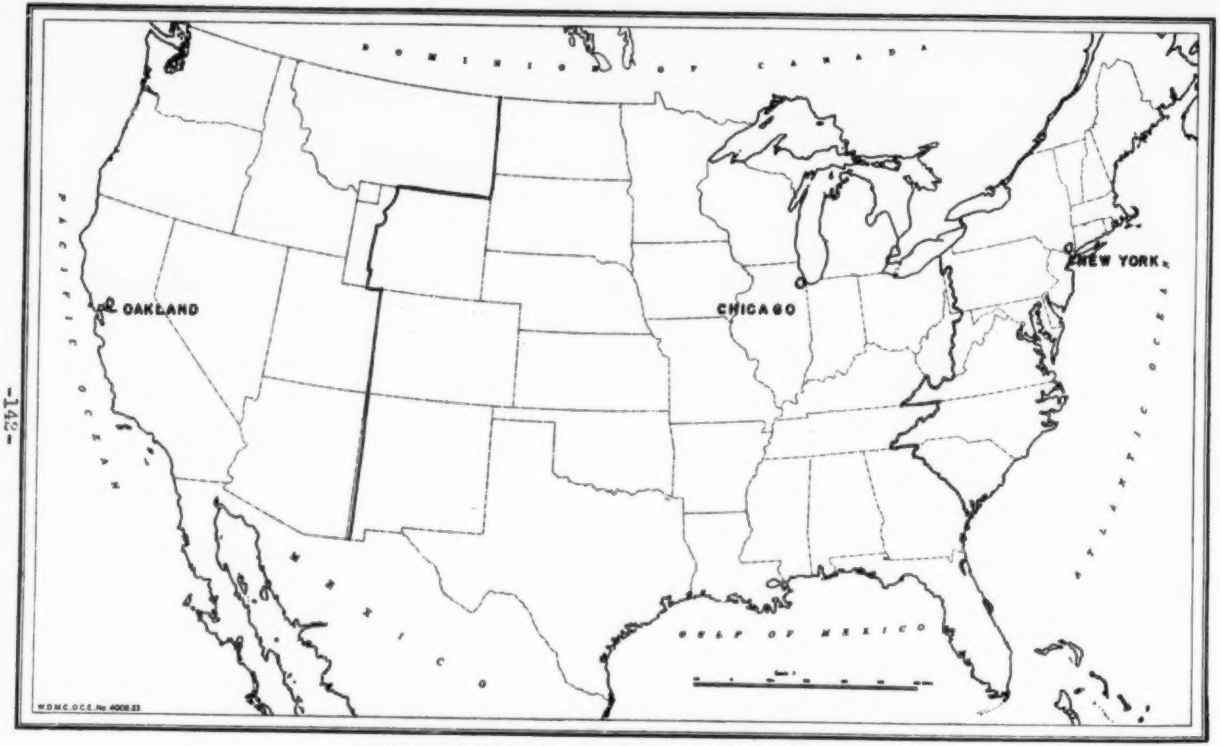

DEPARTMENT of DEFENSE
MUNITIONS BOARD
DEPARTMENT of ARMY
NAVY
AIR FORCE
UNDER SECRETARY
AC of STAFF G 4
G3
G2
G1
PROC DIV
SERVICE
SUPPLY
R & D
QUARTERMASTER
ORDNANCE
SIGNAL
CHEMICAL
ENIGNEER
TRANSPORTATION
SURGEON GENERAL
VET
MED
NAVY INSP SERVICE
FIELD OFFICES for PROCUREMENT and/or INSPECTION

CHART I

160194

ORDNANCE CORPS DISTRICTS

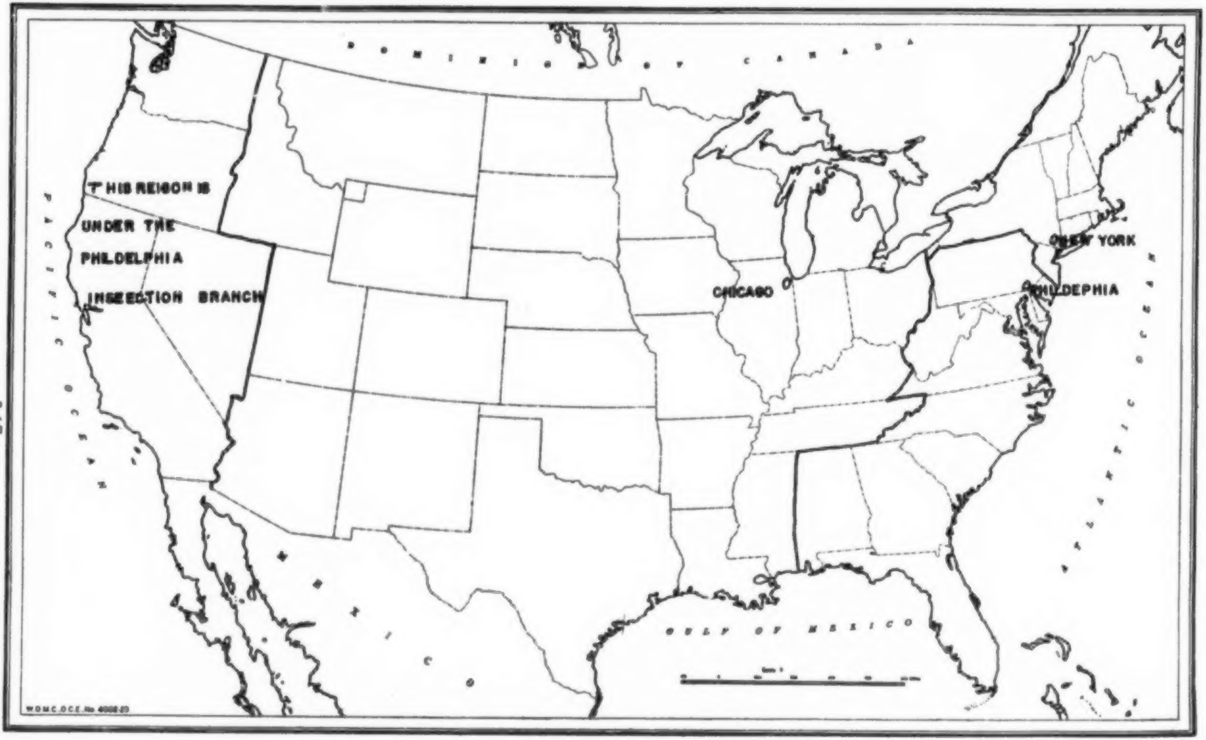
CHART NO 2



QUARTERMASTER CORPS DISTRICTS

160194

CHART NO 3



PRESENT SIGNAL CORPS DISTRICTS

140194

CHART NO 4

PROPOSED SIGNAL CORPS DISTRICTS

160194

CHART NO 4 A

CHEMICAL CORPS DISTRICTS

CHART, NO 5

ENGINEERING CORPS DISTRICTS

CHART NO 6

SURGEON GENERAL VETERINARY CORPS

160184

FIGURE NO 7

OVERALL ARMY PICTURE

CHART NO 8

INSPECTION ON R & D CONTRACT	INSPECTION ON COMPLEX ITEMS	MASS PRODUCED STANDARD ITEMS
REQUIRED MILITARY CHARACTERISTICS SPELLED OUT	COMPLIANCE WITH END ITEM FUNTIONAL REQUIREMENTS	LARGE QUANTITIES
NO DETAIL REQUIREMENTS	SOME CHARACTERISTICS MUST BE INSPECTED TO INSURE LIFE	USUALLY CONTINUOUS PRODUCTION
MUST USE STANDARD COMPONENTS WHEREVER PRACTIBABLE	CERTAIN FEATURES ARE IMPORTANT TO INSURE INTERCHANGE OF COMPONENTS, OR SUBASSEMLIES	ACCEPTANCE BASED ON SAMPLES
USE OF SOME MATERIALS VARY OTHERS BANED		

CHART NO 10

Optimum Operating Characteristic Curve

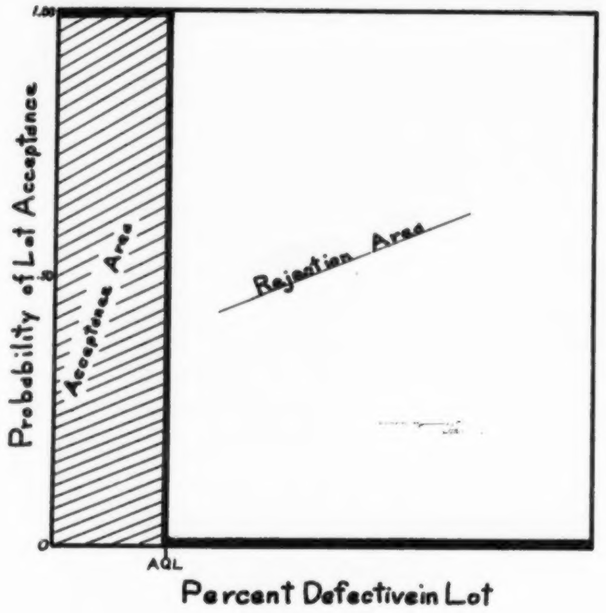


Chart 11

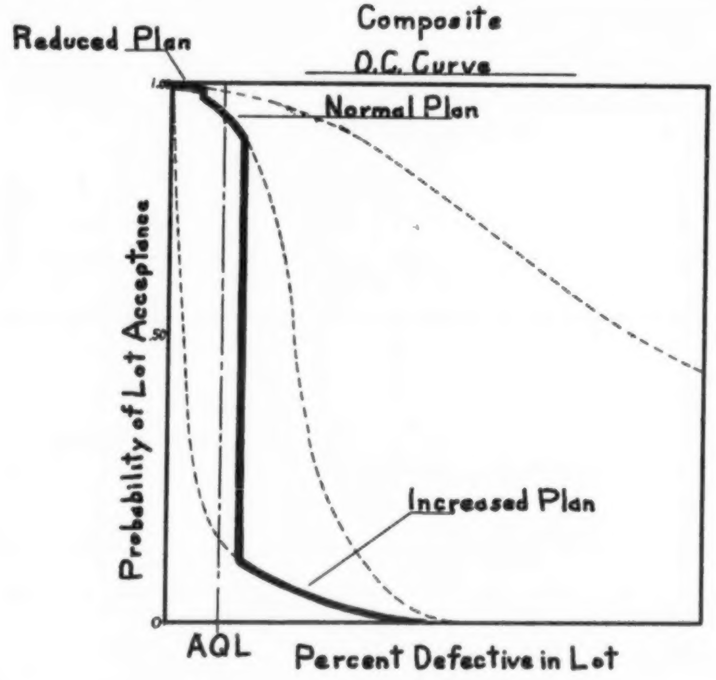
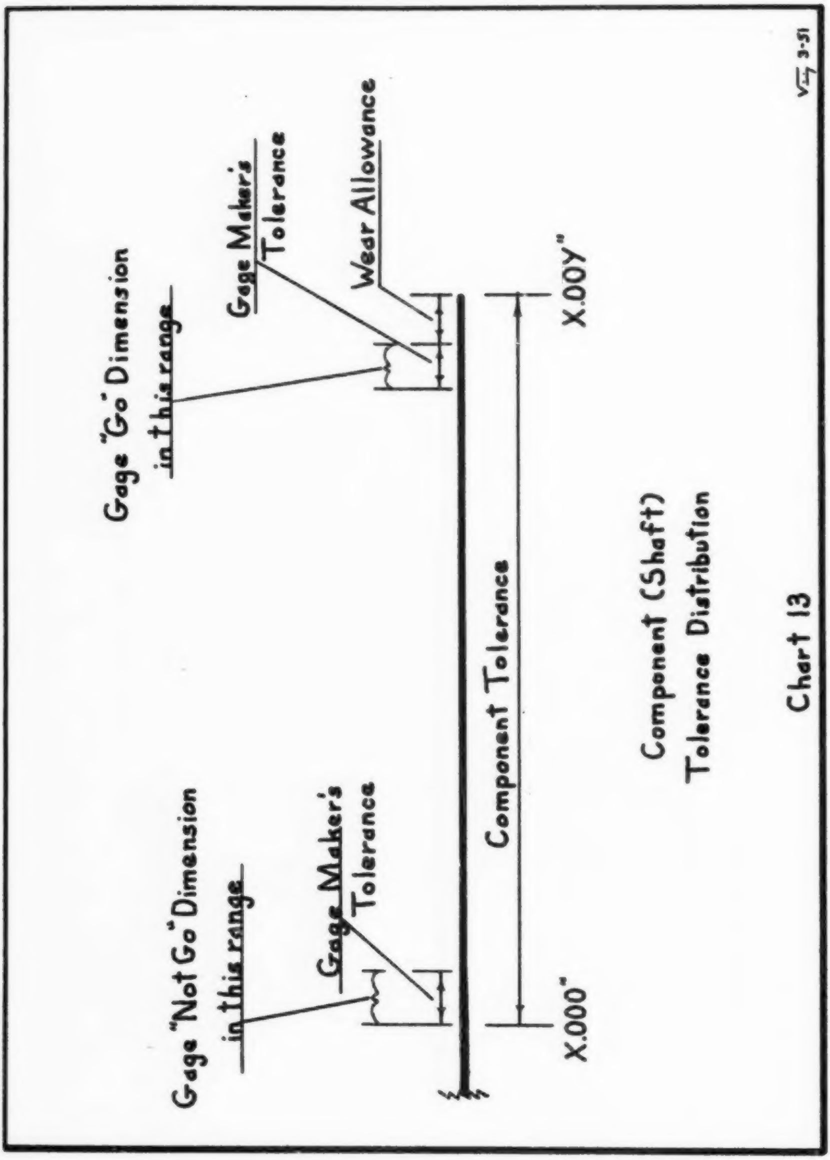


Chart 12

V 3-51



Component (Shaft) Tolerance Distribution

Chart 13

NAVY'S PROGRAM FOR QUALITY CONTROL

Captain Milo R. Williams, USN
Asst. Chief of Naval Material (Field Services)
Office of Naval Material, Department of the Navy

In order to have a program for Quality Control, it is first necessary to have a goal. The Navy has, since its early origin, had for its goal in the field of procurement, the acceptance only of materials which fully comply with the specification. Since those early days, heavy reliance has been placed upon the selection of reliable contractors. However, no matter how reliable the contractor, and the record has not been perfect on that score, the contracting officer has been obligated to discharge his legal and moral obligation to assure himself that the terms of the contract have been complied with. Thus, the inspector appeared on the scene at a very early date.

I would like to stress, at the very beginning, that the Navy has always maintained, and still maintains, that the contractor has the primary responsibility of presenting for inspection materials of suitable quality. Every possible reliance is placed on the technical ingenuity of the contractor to contrive his own methods of producing products of satisfactory quality.

Quality Control naturally starts with the design and preparation of proper specifications. Simple, understandable specifications are most desirable, but, unfortunately, it is often possible to make them too simple if the buyer expects the product received to meet his needs. I recall one case years ago when a certain amount of rock was required for a fill along a river bank. The rock was needed in somewhat of a hurry and it did not matter much whether the rock was large or small, whether it was of high compressive strength, etc. So specifications prepared were superlatively simple, calling essentially for a certain tonnage of rock. The inspection required for quality was practically nil. The low bidder delivered the rock without delay and the first load was hauled to the river bank and dumped. To the chagrin of the engineer, part of the rock floated down the river! The rock was basalt rock so full of gas bubbles that it had a specific gravity of approximately unity.

The important link between the contracting officer and the contractor in material procurement by the Navy is the Material Inspection Service, USN. It is this Service, through its field offices, which accomplishes the field administration of Navy procurement contracts, including the inspections connected thereto.

Both the technical bureaus and the inspectors in the field have sought for years to improve specifications and methods of inspection. Working as a team, steady progress has been made through the years and this progress continues. However, both specifications and methods of inspection have had to be patterned to current production methods generally available in industry. Furthermore, specifications should be as broad as practicable in order to encourage the maximum competition among bidders.

During the past eight or nine years of practice and experimental application of Statistical Quality Control procedures in the Navy system of material procurement, namely, Design, Engineering, Purchase and Inspection of materials, we have come to the conclusion that no time should be lost in making Statistical Quality Control a normal part of the system.

To this end qualified quality control technicians have been employed in the material bureaus, in their laboratories, and in inspection offices — to consider design and engineering problems from a Statistical Quality Control point of view, to include statistical methods of determining conformance in the written specifications and, further, to operate these methods in the field of inspection. The bureaus, by the general and detail specifications developed, make Navy policy.

If the bureaus permit, in the specifications, the acceptance of material upon the submission of a "certificate of conformance", or prescribe any other method of inspection such as an undefined "spot check", that is just what the inspector will do, even though the usual catch-all phrase "use any other means to determine conformance" is also written into the specifications. Now this is not a general condition but I do want to emphasize that we must always be on guard against vague or incomplete specifications.

The inspector is the middleman. He has no responsibility for the specification but he often has to make an interpretation of it. Also he is called upon to explain why defective material got past him when such material is received by the end user. So to keep his own head out of the noose, the inspector, by means of recommendations, suggestions, and personal salesmanship has tried to sell Statistical Quality Control to the bureaus so that he will be protected by sound specifications.

Statistical Quality Control, in the Navy, started in the field of inspection without benefit of portfolio. After much selling, the bureaus organized to provide Statistical Quality Control legally. However, there still remained a time lag in the revision of specifications. To bridge this gap, steps were taken to include statistical sampling provisions in contracts. As of now, I am happy to report that specification revisions including Statistical Quality Control are catching up and it may not be necessary, for long, to retain Quality Control clauses in contracts. The selling campaign has been successful and we are all of one mind in the matter of supporting Statistical Quality Control. I have mentioned these things to explain, at least in part, why statistical sampling developed prior to the other phases of Statistical Quality Control.

Now to get back to my original point in stating the Navy program, namely, "to make Statistical Quality Control a normal part of the system".

We have felt that in order to get the most out of Statistical Quality Control procedures, they must be integrated and become part of the day to day operations of design, engineering, manufacturing and inspection. This may seem elementary; however, take a look at some of the Quality Control installations with which you are familiar. Isn't it true that one or more of these installations has Quality Control assigned in a staff capacity? Quality Control runs special studies and keeps the boss informed on the latest in Quality Control. But look into the actual operations — have the production people, the inspectors, the designers and the engineers adopted Quality Control for their every day work? It is a difficult job, but we believe well worth while. Now speaking for the Material Inspection Service, USN, our program is not only to have a man qualified in Statistical Quality Control in every major field office, but to make Statistical Quality Control an integral part of all our daily inspection operations. The inspection administrator or chief inspector, the technical assistant, and in addition, the itinerant and field inspectors are to

have such a complete understanding of Statistical Quality Control that it will be second nature to them. Statistical Quality Control functions are not to be centered with one man in an office; instead the satisfactory operation of Statistical Quality Control is the responsibility of everyone in the Inspection Department. It may be necessary, for a little while to come, to keep Statistical Quality Control in a staff capacity for training, indoctrination and supervisory purposes, but this is not our final objective. If Statistical Quality Control is to continue to be looked upon as a specialty, then all fully qualified inspectors will have this additional specialty.

It is believed our purpose of making Statistical Quality Control the usual, will better be served if we do not change position titles, for instance the Technical Assistant will remain, and will now carry an additional tool, namely Quality Control procedures, and so on for other inspection positions.

So now you have the picture! The Material Inspection Service, USN operates for and under the technical guidance of the technical bureaus. Its inspectors expect complete and satisfactory specifications and procedures with which to do their jobs; and they offer many suggestions on the adoption of Statistical Sampling. The field inspectors have, through necessity, increased their work-load to become technical advisors in the matter of Statistical Sampling, to the technical bureaus. This operation is continuing with the blessing and, many times, at the request of the bureaus. The majority of the Classifications of Defects, which, as you know, are part of the Statistical Sampling Program, have been made in the field. They are the inspector's interpretation of item requirements, and incidentally, are being promoted by our office as a standardization means. These Classifications of Defects are forwarded to the bureau concerned for approval, or to the Field Services Division (Office of Naval Material) for coordination and promulgation, depending upon the particular circumstance.

In order to support this program, bureau personnel are now writing Statistical Quality Control procedures into specifications and supporting it by other means, such as training of engineers. Quality Control courses are available and have been given on request to government inspectors and also to private contractors where the Navy has an interest. Knowing full well that quality can not be inspected into a product but must be built into it, we have assisted contractors wherever possible to set up "in-process Statistical Quality Control". The pay-off has been better quality with less inspection effort. Our inspectors are further required to know "in-process Quality Control procedures" not only to be better inspectors now, but to be prepared in the event that means are devised for using in-process information as acceptance media. A few specifications now require the statistical analysis of variables data for acceptance purpose and it is expected that this type of specification will increase in number. The bureaus are developing them. We must be prepared to intelligently apply these procedures. The Office of Naval Material has sponsored a film entitled "Quality Control through Statistical Methods" which was initiated to promote the use of Quality Control.

The following specific Quality Control programs will be of interest to you:

There is active now at the Naval Clothing Depot in Brooklyn, which is a Bureau of Supplies and Accounts activity, a program of acceptance by Statistical Sampling procedures. The type of items involved are

clothing of various kinds such as socks, underwear, rolls of cloth, packing items, shirts and so on. The program began very cautiously because no process information was available upon which to base Acceptable Quality Levels, and furthermore, an adverse supplier reaction was expected. The first problem was quickly taken care of by instituting a system of recording the inspection information obtained from inspection branches. Simultaneously, written Classifications of Defects were made available to all clothing inspectors and contractors. Then the desires of the Naval Clothing Depot in regard to Acceptable Quality Levels were made known to the potential suppliers through the "invitation for bid" which subsequently became part of the awarded contract. Note that the same referenced specifications were used that had been prior to the use of Acceptable Quality Levels. The Classification of Defects was not a part of the contract, i.e. did not replace the specification, but served as an instruction to the inspector. The results of the trial runs of this program were so encouraging that it was not long before Statistical Quality Control became a regular part of the purchasing program at the Naval Clothing Depot. We are getting products of higher quality now and have a clearer understanding with suppliers as to requirements. An interesting outcome is that the settlements of contracts are not negotiated as frequently anymore. This may appear to be strange, but prior to Statistical Quality Control it was difficult to make a satisfactory determination of final acceptance.

Secondly, I would like to tell you about another class of items to which statistical sampling acceptance methods are applied. These are medical and pharmaceutical items purchased by the Armed Services Medical Procurement Agency. Acceptable Quality Levels for major and minor defects are furnished the inspector who interprets specification requirements into the form of a Classification of Defects. An additional step that has to be taken in this case is to coordinate the various Classifications of Defects submitted and promulgate what is used as a Uniform Classification of Defects. At the time when Inspectors of Naval Material were first given the responsibility for inspecting medical equipment, we had many complaints regarding unsatisfactory material. It may have been coincidence, but after the break-in of acceptance by statistical methods, the complaints dropped to the point where we are not worried at all. Actually, what I believe happened, was that Statistical Quality Control made possible a clear understanding of item requirements. The inspector knows what is expected of him and the contracting authority knows what to expect from the field.

The Department of the Navy in January 1950 was assigned the responsibility for coordinating and administering, for the Department of Defense, a program of research and development in the field of statistical aspects of Quality Control. The Office of Naval Research was designated as the coordinating and responsible agency for this program for the Department of the Navy. The cost of this program is shared equally by the Army, the Navy and the Air Force and the program will continue for a period of at least four years.

The research aspects of the program are implemented by the initiation of projects at statistical centers, especially those which in the past have expressed interest through strong research activities in the field.

The primary object of the research program is the development of inspection procedures for acceptance sampling and process control for the Department of Defense, which are sound from an economic, administrative and statistical point of view. The program includes a systematic review

of existing procedures, direct extension of the range of existing procedures, and development of methods to handle types of inspection for which standard procedures have not been devised.

In order to motivate the research program, an operational survey of the inspection program of defense agencies began in October 1950 and will continue for the length of the program, in order to keep research personnel abreast of actual procedures. It is important to know, for example, what plans are in wide-spread use; the relative importance of different types of products; the administrative authority for choosing plans in the three Services; the appropriateness of the common probability models used; and the economic factors pertinent to picking a sampling plan.

At present, Stanford University is engaged in the research program, and it is expected that other universities will be included. The progress reports indicate that the major portion of the preliminary efforts have been devoted to urgent specific problems found in the inspection groups of the several agencies. However, more general planning will be included in future operations. For example, an attempt will be made to replace the present Risk Index of cataloguing sampling plans, which essentially measures losses in terms of probability, by another index intended to present the relative cost of inspection. This proposed index will reflect (a) the cost of passing poor material and (b) the actual cost of sampling.

A Sampling Inspection Policy Board has been created by the Office of Naval Research to aid in providing guidance for the program. This Board consists of Professor Allen Wallis of the University of Chicago as Chairman, and two members, Dr. Harold F. Dodge of the Bell Telephone Laboratories and Professor Eugene Grant of Stanford University. For specific problems, "ad hoc" working committees, which will consist of representatives of the three Services, may be appointed.

Since the primary concern of the Bureau of Aeronautics is with Air Force-Navy aeronautical specifications and drawings, it has had to work very closely with the Air Force to the greatest practicable extent in evaluating the practical application of statistical sampling to aeronautical material and parts. Because of the critical nature of so much of the aeronautical material, the application of statistical sampling must be done on an item basis. General application of such procedures has not been possible to the extent that can be employed in connection with non-critical items.

Briefly, the program now underway jointly between the Bureau of Aeronautics and the Air Materiel Command of the Air Force calls for the Classification of Defects and the establishment of Acceptable Quality Levels satisfactory to both Services; coordination thereof with the Aircraft Industries Association; and their inclusion in an Air Force-Navy specification, such as for bolts, nuts, machine screws, rivets, and similar Army-Navy-Air Force items.

It is the opinion of the Bureau of Aeronautics that this policy is basically sound in its approach since it should insure that the application of statistical sampling procedures will become a contract matter. This is a very important consideration, not only when dealing with a contractor's operating executives, but also because of the large amount of cross-procurement of aeronautical materials which is carried out between the Air Force and the Bureau of Aeronautics.

The Bureau of Ordnance uses Quality Control procedures in the design stage, manufacturing, inspection and acceptance of Bureau of Ordnance items. Please note that I also include manufacturing; because the manufacturing and ammunition loading facilities owned and managed by the Bureau of Ordnance have also served as proving grounds for in-process Statistical Quality Control procedures. Statistical Quality Control now is a normal part of their manufacturing. Many of the Quality Control technicians of the Navy and other Services have received training in the Bureau of Ordnance facilities. So we are not only promoting the use of Quality Control for others, but also are using these procedures in our own manufacturing plants.

In addition, the Bureau of Ordnance has a continuous program for isolating inspection problems and determining the applicability of Statistical Quality Control to their solution. The inspection of "complex items" such as gun directors is a particular example. I feel sure that the rest of the Navy has materially benefited by the Statistical Quality Control contribution from the Bureau of Ordnance. There are Bureau of Ordnance representatives here today who are available for further details on the Bureau of Ordnance programs.

The Bureau of Ships makes use of statistical sampling of material for the purpose of obtaining Quality Assurance rather than Quality Control. The difference is partly a matter of definition and partly it arises out of operations and is a result of necessity. The Bureau, as purchaser, is concerned with verifying the contractor's claim, when he presents his material for inspection, that it does conform to the requirements. This is because it is held that the responsibility for Quality Control rests on the contractor who has undertaken to furnish material to a certain description and in accordance with a certain specification.

However, I must tell you of a case where the Bureau of Ships went into a large scale Quality Control program to assist a group of manufacturers. The high tensile steel used in the construction of ships requires alloying elements to produce the required physical properties. Before the war, great dependence was placed on Vanadium but there soon developed a critical shortage and its use for structural plate was prohibited. Metallurgical engineers from the industry suggested the substitution of Titanium. The Bureau of Ships approved and the change over began in 1942. There was no time for preliminary investigations and, consequently, reliable knowledge as a basis for action, had to be produced on the job. The unique feature of the whole program was the establishment by the Bureau of Ships of a Quality Control staff in the Bureau which used modern methods of statistical analysis and computing devices for handling the large mass of complicated data. Through the use of these techniques, the problems were identified, the effects of each element and each process factor were evaluated, a total of twenty-eight variables. A sound basis was established for effective action by the industry and the number of unsatisfactory plates was reduced from thirty-seven percent at the start of the program, to three percent.

A great amount of the material procured by the Bureau of Ships does not come from continuous flow production lines. Also, in many products the procurement occurs at irregular intervals with long periods between purchases. The aim of sampling by statistical procedures is therefore to arrive at a degree of assurance regarding the quality of a particular lot without any knowledge of the quality of the preceding lot or of the following lots. To accomplish this objective, larger samples are necessary

than would be used if the purpose was to detect trends or unusual deviations among successive lots.

Although many measurements are made in the course of government inspection of Bureau of Ships material, the inspectors are seldom called upon to establish acceptance limits by calculating the average and the standard deviation. However, the advantages of inspection by variables are understood and special statistical plans have been incorporated in some specifications. The Bureau of Ships expects to furnish instructions and calculation forms in the near future in order to extend the use of inspection by variables.

From what I have already said, you can see that each of the material bureaus of the Navy are progressing through separate but coordinated programs of using Statistical Quality Control to the maximum practicable extent.

The whole problem of assuring full compliance with specifications reminds me somewhat of the story of a mother who was trying to buy a suitable toy for her four year old son. A salesman offered a certain toy for her consideration but she demurred saying "Isn't this a bit complicated for a small boy?" The salesman replied, "Madam, in this day of complicated living one must provide toys which will develop the talents of our children so that they will be prepared for life's trials. Now take this toy — a child can put it together in many ways but no matter how he puts it together it will never be one hundred percent correct!"

In conclusion, I want to say that the Navy has full confidence in our progressive American industry to make the maximum use of Statistical Quality Control methods. By so doing, industry will be helping itself, by presenting for acceptance materials which meet, with the minimum of rejections, the requirements of the Navy. The Navy will continue to encourage this by revised specifications and such modifications of inspection procedures as are warranted while maintaining the necessary assurance of quality of material accepted. In these days, it is essential that all methods and procedures which contribute to greater industrial efficiency and to the increase of our national preparedness must be exploited to the maximum. This is a program in which industry and the Navy, as well as the Army and the Air Force, must and will cooperate to the benefit of all.

TYPICAL QUALITY CONTROL APPLICATIONS AT DELCO PRODUCTS

Leo J. Nartker
Delco Products Division, GMC

At Delco Products we use the statistical techniques of Quality Control as tools for the purpose of improving quality and of reducing costs. Like all precision tools, these techniques must be used carefully. A tool that is ideal for use in one situation may not achieve the same desired objectives in another. This is true of statistical tools, as well as of carpenters' tools, plumbers' tools, machine tools, etc.

In order to determine the effectiveness of our Quality Control applications, we frequently review the results to decide if the statistical tools used are efficient from a quality and cost standpoint. In this presentation, I will show two situations where the same statistical tool was used. In one case this tool was very effective; in the other case, changes were necessary before results could be obtained. These examples will be presented in detail to show some of the problems we had and how we applied the principles and techniques of Quality Control at Delco.

Before going into the examples, we should perhaps review briefly the Quality Control setup at Delco and its relationship to the regular inspection organization. In our plant we have more than 8,000 employees, of which approximately 6,000 are productive operators and approximately 600, inspectors. This inspection organization includes inspectors in our receiving inspection department who use sampling inspection techniques on purchased parts and materials; inspectors in the various parts and subassembly departments who use sampling and occasionally 100% inspection depending on conditions; and inspectors in final assembly departments who perform 100% inspection on the final products.

This Inspection organization is supplemented by the Quality Control Section, which consists of a small staff of trained S.Q.C. analysts. This staff has two functions: first, it acts as a service group to the Inspection departments, supplying them with the most up-to-date statistical methods and techniques; and, secondly, it acts as a fact-finding group, investigating and reporting on Quality problems whenever they appear in the plant. On quality analysis problems we make a thorough investigation of materials and processes and report our findings and recommendations to all affected by each problem. As a result, the Quality Control section frequently functions as a liaison between the various service, production, and inspection departments, co-ordinating information and reviewing results.

In the application of S.Q.C., we are concerned with problems of cost and quality, and we must frequently make decisions concerning the element of risk. This cost - quality relationship has to do principally with parts and sub-assemblies within the plant, since it is not too difficult to evaluate in dollars and cents the cost of inspection to prevent a defective reaching the assembly department, as compared to the cost of a defective being assembled. However, our final products are inspected 100% for performance, and, in general, we expect to continue this practice. We feel that the cost of a defective unit reaching the customer can be so expensive, measured in terms of good will, that this risk must be a minimum.

The statistical tools we most frequently use at Delco are Frequency Distributions, Sampling Plans, and Correlations. We also use the Control Chart techniques for analysis and quality improvement, as well as for the maintenance of process control.

The examples I would like to present today show the applications of control charts and sampling plans. The first example covers the use of $\bar{X}$ and R charts and sampling plans on a diamond-boring operation. The second example involves the use of $\bar{X}$ and R charts and sampling techniques as we have applied them to a turning and cutoff operation on automatic screw machines.

The pieces involved are the rod guide and the piston rod, both parts of the direct acting type of shock absorber used in most new cars today.

* * ROD GUIDE * *

The rod guide is a small aluminum cylindrical piece with a hole through the center concentric with the O.D., through which the piston rod slides when the shock absorber is in action. The piece is made from bar stock on an automatic screw machine. Following this, the I.D. and tenon are finish-machined on a Heald borematic and the pieces are then inspected 100%.

From an operational standpoint, the important dimension on this piece is the I.D., since a small I.D. will impair the normal action of the shock, and a large I.D. will contribute to oil leakage, and hence shorten the life of the shock. Therefore, our problem was to control this I.D. dimension.

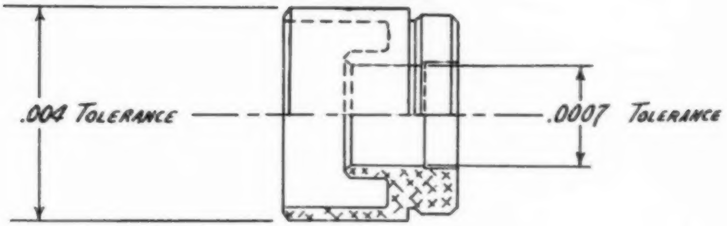
A preliminary investigation showed that the borematic operators were using plug gages to measure a .0007" tolerance. Air gages were provided at the machines, and this resulted in some immediate improvement in quality.

The borematic has four spindles and four sets of tools, which means that four pieces are machined at a time. For this reason, when study charts were put on the machine, a sample size of eight was used, two consecutive pieces from each spindle. The initial charts show that the $\bar{X}$ line for all machines was very erratic. This is illustrated in Figure I.

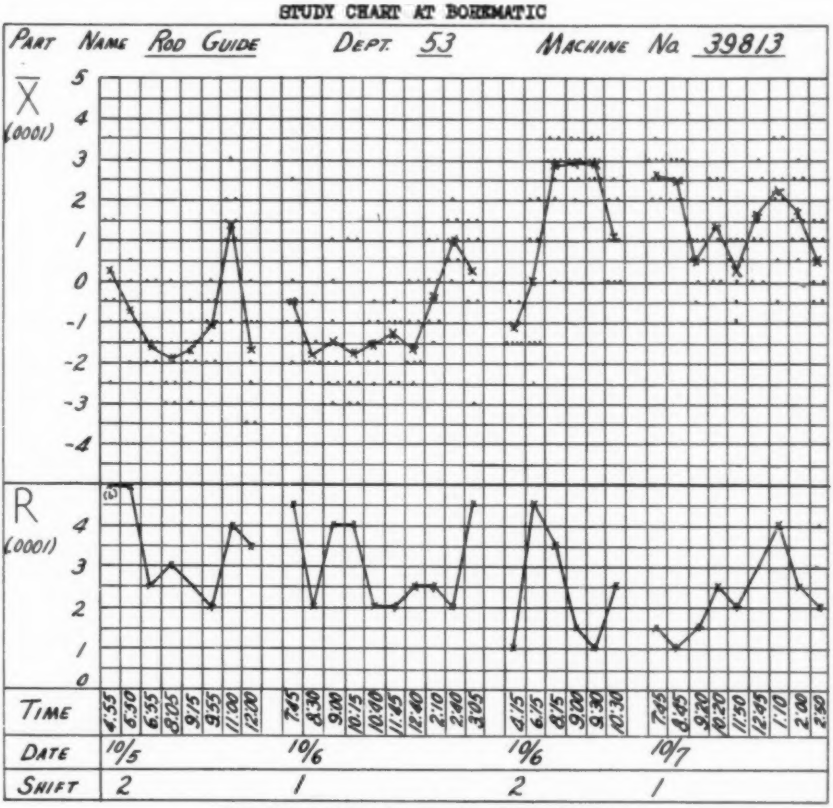
We made our first calculation for control limits with the following results. The value for $\bar{\bar{X}}$ was +.00002, $A_2\bar{R}$ was .00010, σ' was .00010, and $D_4\bar{R}$ was .00052". Since the spread of six standard deviations was .0006", it appeared that the process was capable of holding the specified tolerance of .0007". The grand average was slightly above the spec. midpoint; however, we used $\bar{\bar{X}}$ equal to 0 when calculating the control limits. This seemed justified since the operator can readily control the average level of this process by simple tool adjustments. Centering the control limits about the spec. mean is standard practice at Delco on this type operation where the average level is in control of the operator. Deviations from this practice are sometimes made. In these cases the value of $\bar{\bar{X}}$ is set, not necessarily on the basis of past data, but on the comparison of costs between the value of scrap, as represented by pieces beyond one limit, as compared to the value of reoperation, as represented by pieces beyond the other limit.

FIG. I

ROD GUIDE



STUDY CHART AT BOHEMATIC



CONTROL LIMITS BASED ON ABOVE CHART

For $n = 8$:

$A_2 = 0.37$ $d_2 = 2.85$

$D_4 = 1.86$ $V = 1.94$

$\bar{R} = .00028$

$D_4\bar{R} = .00052$

$A_2\bar{R} = .00010$

$\sigma' = .00010$

$V\sigma' = .00019$

Reject Limits $= .00016$

The control limits of ±.0001, if applied to the data on Figure I, show only a few averages within control. However, these limits seemed to be definitely closer than necessary. Reject limits (1)--sometimes called modified control limits--for this process were calculated to be ±.00015" and these are the limits we assigned to the control chart. Meanwhile, steps were being taken to improve the process. Discussions with the borematic operators indicated that improvement in quality was unlikely unless parts coming to them were improved. An investigation proved that variations in the O.D. of the pieces were so great that occasionally the diaphragm chucks on the borematics could not grip the pieces properly. Too large an O.D. distorted the piece, and too small an O.D. caused the piece to slip and jam up in the chuck, resulting occasionally in tool breakage.

In order to improve the O.D. at the first operation, attribute charts were set up at each of the automatic screw machines. The characteristics checked were the O.D., rough machined I.D., and visual. Control was established through the cooperation of department personnel. Not only the O.D., but also the I.D., after rough machining became more consistent. This improvement was reflected at the borematics as a more uniform depth of cut and a more uniform tool pressure, resulting in fewer tool adjustments and less tool breakage.

The control chart data, as shown in Figure II, definitely shows the effect of these improvements. You can observe that every average (indicated by X) and most of the individuals fall within the control limits. The individual points are represented by the spindle number from which they were taken. This method of plotting each spindle was tried out to determine what part of the variation at the borematic was spindle variation, and what part was due to differences in settings between spindles. It also gave the operator an indication of which set of tools was likely to need adjustment first.

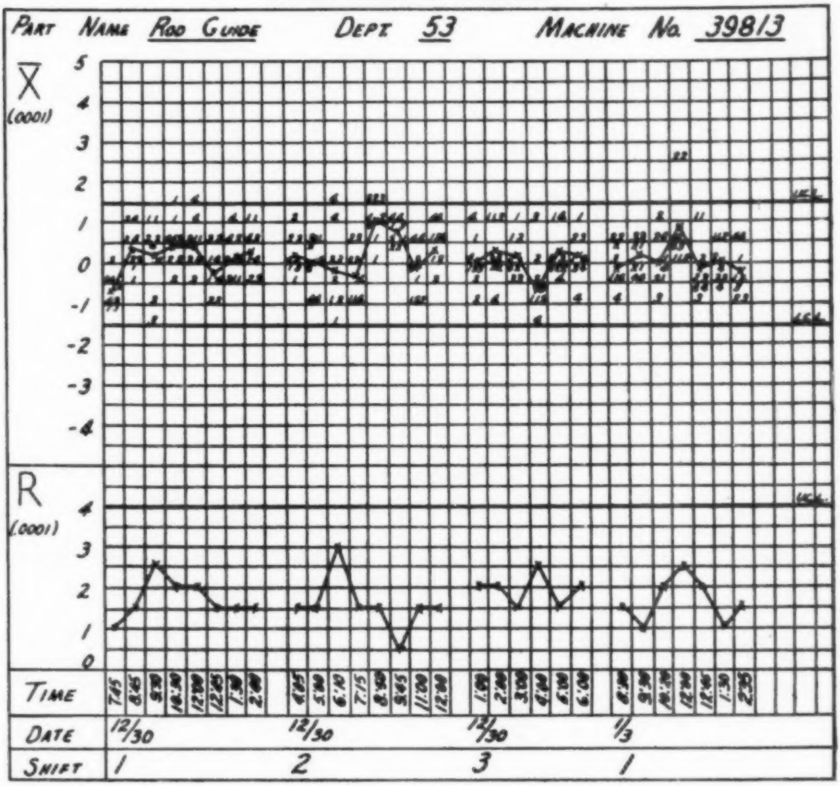
An examination of the control charts indicated that all borematics were in control to the extent that, not only the averages, but nearly all the individuals, were within the limits. This situation should be reflected in fewer rejections at inspection, and this was found to be true. However, the inspectors checking every piece were still finding approximately 1% defectives in some trays when the control chart indicated this should be definitely less than .3%. An investigation was made to determine why.

An examination of the pieces rejected showed that most of these pieces were very much out of tolerance. When the operators were informed of this fact, they revealed that their setup pieces were always tossed in with the good pieces, because there was no provision for disposition of scrap, and the lots were always 100% inspected anyway. Following this a tote pan was supplied each operator for defective pieces, and as a result, the percentage of rejections at inspection was definitely reduced.

At this point, a sampling procedure was substituted for 100% inspection, with the provision that all rejected lots be detailed by the inspectors. It was soon evident that rejected lots usually came from the same operator. When production supervision were confronted with this situation, they agreed to a procedure whereby all rejected lots were to be detailed by the operator producing the lots. This arrangement definitely resulted in fewer rejected lots, largely due to the cooperation of supervision on the job and the operators themselves.

FIG. II

CONTROL CHART AT BOREMATIC



SAMPLING PLAN FOR ROD GUIDES

Obtain a sample from each basket of rod guides in accordance with the following plan and check:

1.) I.D.
2.) O.D.
3.) Eccentricity (.002 Max.)
4.) Visual for burrs on O.D. & I.D.

n_1 - 35 Acc$_1$ - 1 Rej$_1$ - 5
n_2 - 70 Acc$_2$ - 4 Rej$_2$ - 5

In this example, we used the control chart with reject limits as a tool to aid in obtaining the specified quality. Also a 100% inspection operation was replaced by a double sampling plan based on the 2% AQL Table (2). The specific plan used is shown in Figure II. The application of these statistical techniques, along with the necessary action by supervision and production operators, produced two benefits: first, a reduction in inspection time which, for the quantity of parts involved, resulted in a considerable savings; and secondly, an improved quality in our final product.

* * PISTON ROD * *

Following the successful application of control charts on the rod guide, we decided to try out this technique on other similar processes. One such process was in the production of piston rods for shock absorbers. New equipment had recently been purchased for this operation; however, it did not seem to be capable of holding the print specifications. This equipment was very similar to the borematics used on the rod guide in that it was a four spindle machine, each spindle having a complete set of tools. The chief difference between the two was that the borematic operated on semi-finished pieces held in a diaphragm chuck, while the new automatic used bar stock.

We also had two other types of automatic equipment producing rods, a six spindle machine with one complete set of tools, and a single spindle machine. Our problem was to determine the capabilities of the three types, and to control the variability of the new equipment if it seemed excessive as compared to the other two.

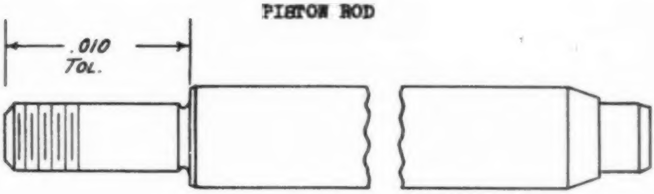
Study charts were installed on all machines of the three types, and data was collected on three characteristics. One of the characteristics had a .010" tolerance and was selected to represent the typical problems encountered. This characteristic is the dimension from the shoulder to the end of the rod (see Figure III). The following are the results for an average machine in each group.

Type Equipment	N	$\bar{R}$	$A_2\bar{R}$	σ'	$6\sigma'$	Reject Limits
6 spindle (1 set of tools)	6	.0030	.0014	.0012	.0072	.0029
1 spindle (1 set of tools)	4	.0022	.0016	.0011	.0066	.0034
4 spindle (4 sets of tools)	8	.0058	.0022	.0020	.0120	.0010

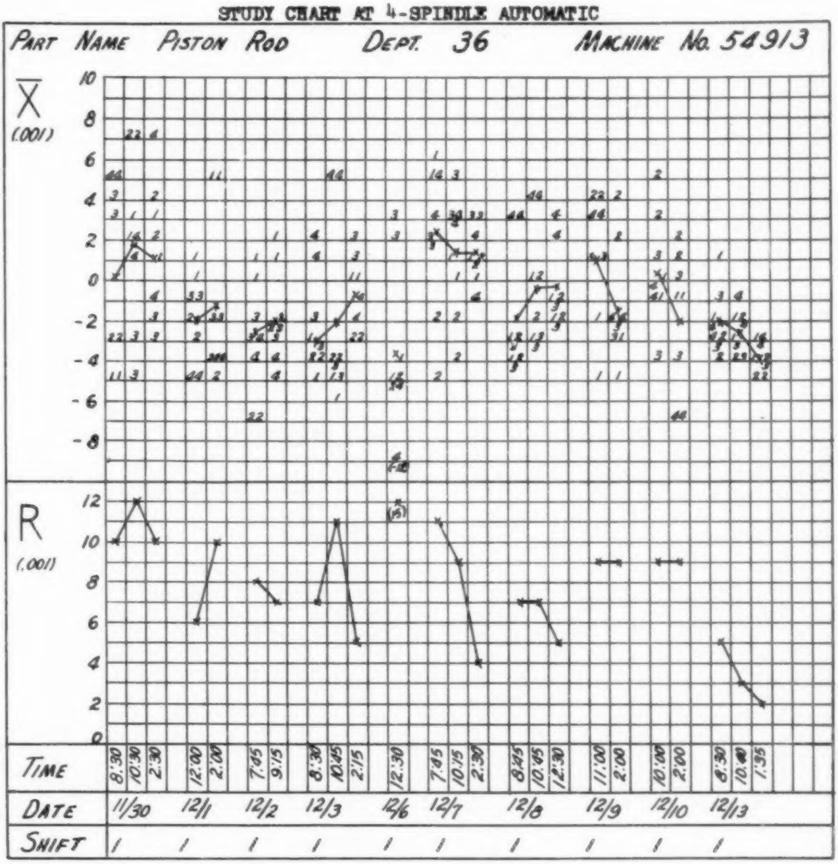
A large difference in $\bar{R}$ is apparent. Although differences in sample size might account for some of the variation, the major portion seemed to be in the type of equipment. The other machines of the same type varied little from the value shown. For example, the greatest variation within types was on the four spindle machine, and this was from .0055 to .0067.

An examination of the data shows that the four spindle machines were not capable of maintaining the .010" tolerance, since the spread of six standard deviations is .0120". Our problem now seemed to be how to control the variability of this type machine.

PISTON ROD



STUDY CHART AT 4-SPINDLE AUTOMATIC



CONTROL LIMITS BASED ON ABOVE CHART

$\bar{R}$ = .0079 $A_2\bar{R}$ = .0030 $D_4\bar{R}$ = .0148

Control charts were placed at the machine, and at the same time, we made frequent analyses of the process using different types and methods of tooling. We noticed that the wide variation in range seemed to be due to the difference in levels among the four spindles rather than to the inherent variation within spindles. In other words, the large range was not due to inherent machine variation, but to the difference in settings between the various spindles. To check this, we increased our sample size for a short time to 16, four consecutive pieces from each spindle. The spindle variation was much smaller than that of the machine, and was comparable to the variation of the single spindle equipment.

Following this, we selected one machine and insisted that the tool and machine settings for all spindles be kept relatively close to the spec. midpoint. This was continued for only a short period with excellent results in terms of keeping averages within limits on the control charts. However, to maintain these limits, it was necessary for the operator to adjust his tools frequently, especially since three characteristics were involved, with four complete sets of tooling, which meant that there were twelve possible adjustments. To make an adjustment, it is necessary to shut down the machine, stopping all four spindles. Consequently, this procedure caused a definite decrease in production. This was demonstrated to us time and again. In every period during which the machines were kept constantly in control, production decreased to such a point that this procedure proved impractical.

One solution seemed to be to open the control limits by using reject limits based on the average σ per spindle, and then make sure that all spindle averages were kept within these limits. The reject limits calculated to be $\pm .004"$, but this seemed to involve too much risk. Many previous control charts would have shown spindle averages within these limits, and we knew that the assembly department had not always been satisfied with the rods they received. It seemed that any less rigid limits would only aggravate the situation. Eventually we discontinued control charts on these operations and substituted sampling.

We sampled every box of rods produced by each operator on each machine. Each box contains 100 to 150 rods lined up side by side. The inspector visually checks the lot and then selects four pieces to be gaged on all dimensions. These four rods are not necessarily a random sample, since the inspector deliberately tries to pick out the defective pieces. If one rod of the four is found out of tolerance on any dimension, eight others are selected which might appear to be out on the same characteristic. If another defective is found, the lot is returned to the operator for sorting. This sampling procedure proved very effective in reducing rejections and in eliminating complaints of defective rods from the assembly department.

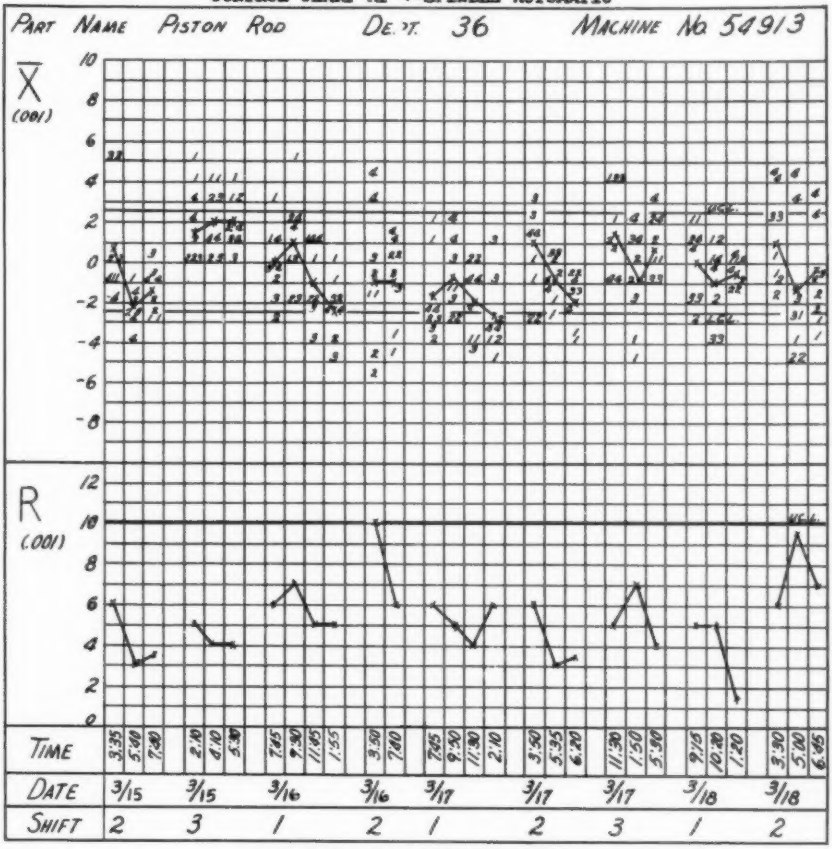
In this example concerning piston rods, the $\bar{X}$ and R charts could not achieve the anticipated improvement unless production was sacrificed. However, the substituted sampling plan has achieved acceptable quality economically and with a minimum of risk. This procedure, by returning rejected lots to the operators, keeps them alert to the specification limits and requires them to inspect their own work more frequently in order to utilize the entire tolerance and yet avoid producing out-of-spec. pieces.

FIG. IV

CONTROL LIMITS BASED ON AVERAGE RESULTS

$\bar{R}$ - .0058 $A_2\bar{R}$ - .0022 $D_4\bar{R}$ - .0106

CONTROL CHART AT 4-SPINDLE AUTOMATIC



SAMPLING PLAN FOR PISTON ROD

Obtain a sample from each box of piston rods in accordance with the following plan and gage on all dimensions:

n_1 - 4	Acc_1 - 0	Rej_1 - 2
n_2 - 8	Acc_2 - 1	Rej_2 - 2

As shown in the examples of the rod guide and the piston rod, Delco is using statistical techniques successfully. However, it has been our experience that these statistical tools cannot be used haphazardly or by rule-of-thumb. Each application must be analyzed individually and results must be reviewed frequently to determine if procedures should be altered or discontinued. A thorough knowledge of the statistical techniques available, of how they are used, and what they can do, combined with an understanding of the operations to which the techniques are to be applied, usually results in gratifying accomplishments. We at Delco are convinced that statistical techniques are tools, and can be a major influence in economically producing higher quality products.

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1. Statistical Quality Control - by E. S. Grant, p. 215-217.

2. JAN - Std. 105, Table G.

PEOPLE, PISTON RINGS AND QUALITY CONTROL

Carl E. Hoover
Perfect Circle Corporation

Modern Quality Control has been, is being and probably shall continue to be hearlded as one of Industry's most potent tools and properly so. By now we should be past the stage of having to sell its value to each other within our Quality Control organization. Like any sharp tool, it will 'cut' the user if improperly handled.

Assuming we possess a good working knowledge of the techniques and their application we are often quite shockingly confronted with the realization that our control charts, frequency distributions, histograms etc. won't fix anything by themselves. They'll point out where, when and with imagination, experience and ingenuity sometimes what is the matter, but they won't fix anything.

When we are enjoying the thrills of watching a smooth operating football team click, play after play, we either don't see, or fail to realize, the hour upon hour of drill on the fundamentals, that makes stellar performance possible.

What fundamental then must we spend hour upon hour practicing? Who is it that must fix or correct the discrepancies pointed out by control charts and various other means of analysis if we're to get this Quality Control job really put to work? Why it's Tom and Joe and Pete and Al and Steve and Mary and Wanda and Rose! People! Folks! They are human beings just like you and me. Since that is so we must know something about them.

Here are the peculiarities, thinking and habit patterns of 75%, three out of four of the folks with whom we come in contact.

(1) They worry a lot, (2) their feelings are hurt easily, (3) they are very deliberate in everything they do, (4) they resent being ordered to do anything, (5) they are urged to their greatest efforts by praise, (6) they are suspicious of the motives of others, (7) they are radical in religion and politics, (8) they would rather struggle alone with a problem than ask for help, (9) they would rather work alone than with others, (10) they prefer reading to athletics or any 'big muscle' activity, (11) they day dream a lot, (12) they are poor losers, (13) they prefer meticulous detailed work, (14) they are moody, and (15) very conscientious.

The habit and attitude patterns of the other 25% of the folks is the opposite of those just given.

There is one predominant characteristic inherent in everyone and that is the unconscious desire for IMPORTANCE. Although we are reluctant to admit it, the desire for importance is responsible for our going on and on when we are asked how we spent our vacation or our advise on some subject is sought. We stayed around home an extra day or so after getting over a light sick spell. Why? So Mother and the kids would solicit our comfort and general well being. We hobbled back to the shop or down to the corner on a bad sprain or with an arm in a sling! Why? To give folks an opportunity to ask us about the injury so we could go on and on and

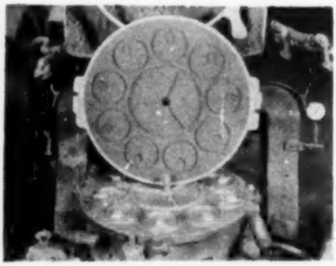
satisfy our unconscious desire for IMPORTANCE.

Little folks are very brazen, we think, about getting this desire satisfied. They say, "watch me, I can do this," or they are very naughty to gain attention.

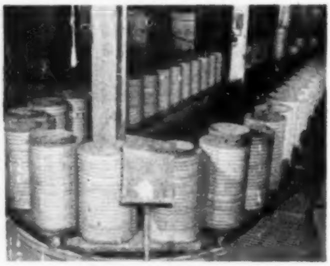
Big folks are just as persistant in getting their desire for importance satisfied but they go after it a little more subtley.

You and I can satisfy that desire for importance, inherent in people. How long has it been since you gave anyone a sincere compliment? Don't answer that. Just practice it a while. It will elevate you in the minds of other people and will give you a glow of satisfaction inside for having done it, the like of which cannot be attained in any other manner. Beginning now, play like everyone you come in contact with has a sign hanging around his neck that says, "Make me feel important."

Let's take a quick look at some of the processes that bring a Perfect Circle into being.



Impressions of a ring pattern are made in sand on a molding machine.

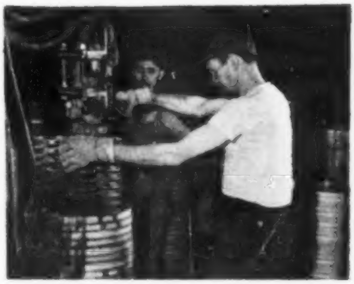


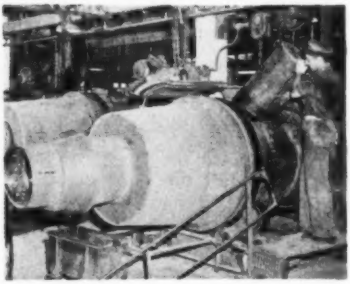
These molds are placed one on top of the other 20 molds high.

The stacks move around a loop conveyer where they are filled with molten iron.

The conveyor brings the molds on around to the shakeout station.

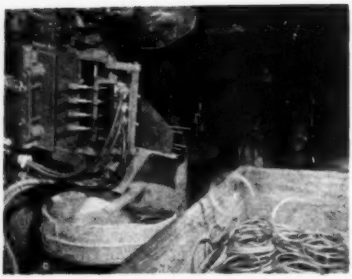
The ring tree is lifted out of the flasks. The sand vibrated off and the rings stripped from the tree into barrels.



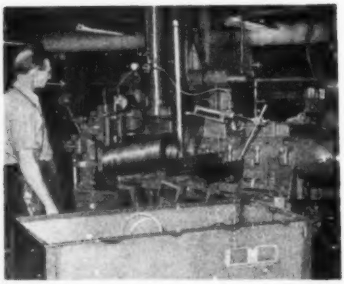


The castings are taken to cleaning mills where they are tumbled and turned with cleaning stars in long cylindrical rotating tunnels.

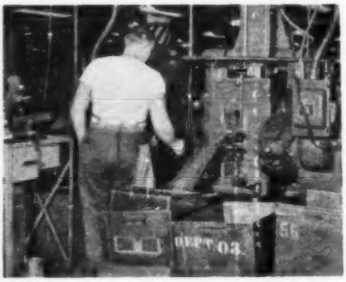
The castings are inspected.

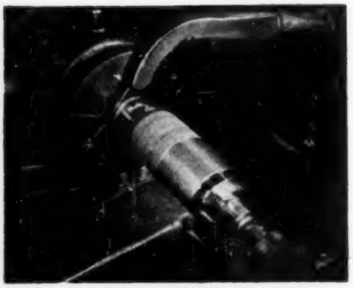


The grinding removes approximately .012" from the edgewidth dimension.

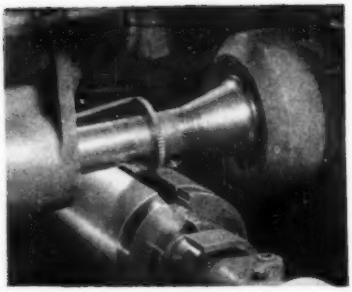


The rings are then sent to the machining plants where the first operation is grinding. This operation finishes the edgewidth dimension to plus and minus .00025" with a micro inch finish of 25. Max.



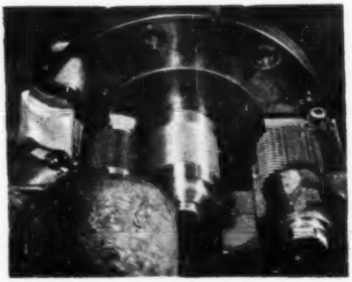


At the form turning operation stock is removed from the O. D.

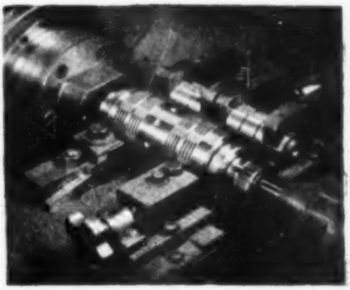


Also at the form turning operation the Gap is milled.

Boring operation removes stock from the I. D. of the rings.

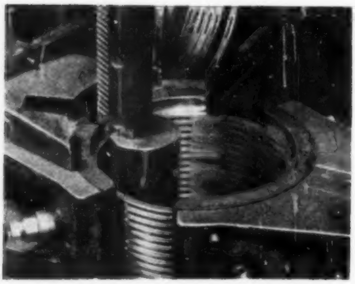


Grooving, channels and mills the slots in Oil rings.



Finish Turn, final dimensions the Wall characteristic and contours face.

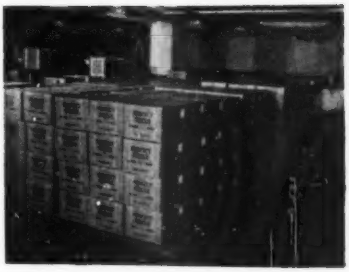
Broaching sizes the final dimension in the Gap.



After final Inspection the rings are oiled, rolled, and labeled.

They are then sent to the Warehouse. Rolled Stock is checked out against orders for Original Equipment Manufacturers.

Boxed Stock is checked out against orders for Jobbers and Dealers in the Replacement Field.



The initial spade work for Quality Control was done in the Grinding department. #226 Besley Grinders are used, having horizantal spindles supporting 30" vertical discs and each driven by a 25 HP. motor. The discs turn in opposite directions, the motors are reversible. Rings are fed between the discs, vertically in guide bars by a mechanical feeder up to 400 per minute. An unwritten law told operators to grind to the high limit. (You can take more stock off if necessary, but you can't put stock back on.) Standard practice was to make adjustments to the machine on the basis of the measurements of one ring with micrometers. So the operators measured a ring and made one of three decisions, adjust to remove more stock, adjust to remove less stock, leave it alone. It was found, that on this basis, operators were making the wrong decision two times out of three and when they decided to make an adjustment they were adjusting in the wrong direction half of the time.

The first step toward correcting the situation was to provide each operator with his own Sheffield Gage, instruct him to shoot at the middle of the spec and to make adjustments only on the basis of the average of the measurements of five successive rings.

Inherent variability checks showed that the machines were capable of doing the job they were being asked to do, but operators weren't holding the limit because they couldn't find the middle of the spec.

Rings came out of the machines on to long stakes, one after the other. When a stake was full the rings were placed in neat rows in a pan. Machine adjustments had the effect of stratifying the grinding level and as a consequence pans containing rows of rings, many rows at different

levels, the result being that operators were chasing the levels of the rows in the pans, and were keeping within a tolerance more than twice the spread they should have been. By removing the stakes and running rings loose into big boxes, they become 'Homogenized' so the operators can now set their machines for the proper stock removal and maintain that level with a minimum of adjustment.

Supposedly everything should have been alright, but inspection began finding undersize rings in increasing numbers, far more than oversize. The finish grinding mean and the inspection mean were the same, also the tolerance. Following grinding there is a washing and drying operation. It was found that rings having a '0' mean after Grinding, had a minus .00005" mean at Inspection. All rings on the low limit after Grind were undersize at Inspection. By raising the Finish Grind mean plus .00005" above the Inspection mean the results of much striving were finally made evident.

Before control scrap was 3.82%. After control was obtained and currently scrap is .42%. Cleared to started before control was 96.18%, after control 99.58%. Cost of scrap at this location $1000 per % per month. Cost of Grinding before Control $1.52/M, after control .31¢/M. Inspectors before control 28, after control 2.

Many similar stories could be told about most of the other operations, time permitting. From our standpoint the manufacturing problem is not that of making a piston ring. Rather it is the problem of making hundreds of thousands of piston rings whose quality characteristics will distribute themselves uniformly around the centers of the dimensions specified.

Quality Control is a set of statistical tools with which we can go to a machine or process and find what it is doing and what it is capable of doing regarding the quality characteristics it is contributing to the product.

In seeking out assignable causes and doing our idea hunting let's not overlook the obvious. Once a truck came barrelling down the street to an underpass. Due to insufficient clearance the truck became wedged tight. Traffic was tied up, horns screamed, cops came, wreckers tried to pull the truck loose, pandemonium reigned. A small boy distracted from his sidewalk play yelled at the cursing 'Truck Driver', "Hey mister, why don't you let the wind out of your tires?" Out of the mouths of babes.

Let's remember then, that the fundamental in getting our task accomplished, of putting Quality Control to work practically, is people and people are funny, they're no good, but they are human beings and it's our responsibility to understand them, to know what makes them tick!

Have you ever been so provoked, irritated, down right mad at something one of your kids did or didn't do that you've determined to lick the pants off of him? Then the little fellow rushes in from somewhere, throws his arms around your neck and says, "I love you, Daddy." I'll bet you didn't touch him.

Did you ever try beating your boss to his 'Sunday' punch with a sincere compliment? He's a human being too, you know.

There is so much good in the worst of us and so much bad in the best of us, how can any of us judge all of us.

Our prayer everyday, several times a day should be: Give us the patience to accept those things we cannot change, the courage to change those things that can be changed and the wisdom to know the difference.

TWO SIGMA OR THREE SIGMA?

Harold A. Freeman
Massachusetts Institute of Technology

Errors of the first and second kind

This is to be an elementary and expository account of some of the statistical consequences of the location of control limits.

From an operational point of view a quality control chart may be regarded as an upper and lower boundary on a function of the sample data. These boundaries are often called control limits. Whenever the function of the sample data lies outside these limits, action on the process is taken; otherwise, action is not taken.

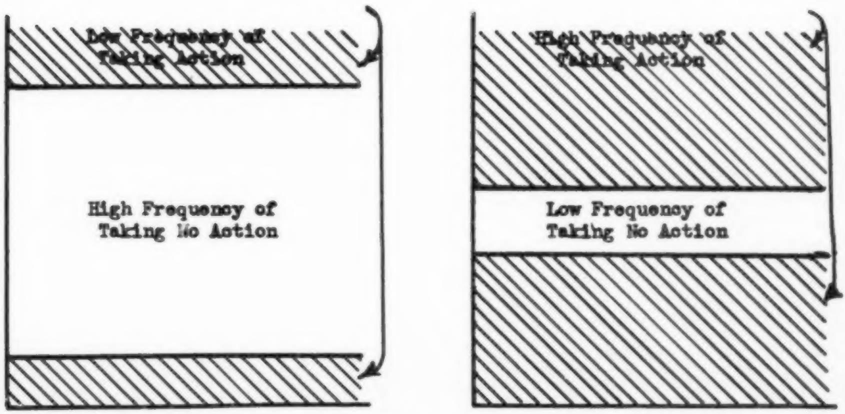
The general nature of the problem of locating control limits and of the errors involved is easy to see. If the process is in control, no action should be taken. But each time the function lies outside the control limits, action is taken. Therefore, if the process is in control, the control limits should be far apart in order to minimize the frequency of taking unnecessary action. Taking action when a process is in control will be called an error of the first kind.

If the process is out of control, action should be taken. But such action is not taken whenever the function lies inside the control limits. Therefore, if the process is out of control, the control limits should be close together in order to minimize the frequency of not taking the necessary action. Failing to take action when a process is out of control will be called an error of the second kind.

The effect of the location of control limits on the frequency of taking action is illustrated in Figure 1.

Figure 1

Effect of Location of Control Limits on Frequency of Taking Action



Note that it is impossible to hold down both kinds of errors. Spreading the control limits reduces the frequency of errors of the first kind but increases that of errors of the second kind; bringing the control limits close together does the reverse.

Limitations on the Usefulness of Measuring the Frequency of Errors of Both Kinds

The existence of errors of the first and second kind is clear enough, and it should also be clear that such errors are with us forever. The frequency with which they occur can be determined only if the statistical nature of the quality control chart is more closely defined; later in this talk, I shall describe, in a simple case, the nature of the required refinements and the process of measuring the frequency of errors. But I would first like to note that, occasionally, quality control charts which have not been meticulous as to the frequency of these errors, have been effective. In certain crude situations, the mere plotting of the sample data, without concern for the location of control limits, has lead to the removal of sources of defective product. Such a "control chart" is hardly optimal, but I mention it to indicate that mere systematic book-keeping of sample quality data—which is all that the procedure of the preceding example amounts to—has led to improved quality. Second, we must keep in mind that the assumptions which will later be found necessary to permit the determination of the frequency of error may be so imperfectly realized in the production process as to leave doubtful the practical relevance of such determinations. Finally, the location of control limits is clearly a matter of costs—the cost of looking for trouble when there is none compared with the cost of not looking for trouble when trouble exists—and these costs can be so uncertain (for example, what is the cost of selling defective product?) that interest in the statistical aspects of the location of control limits may be discouraged.

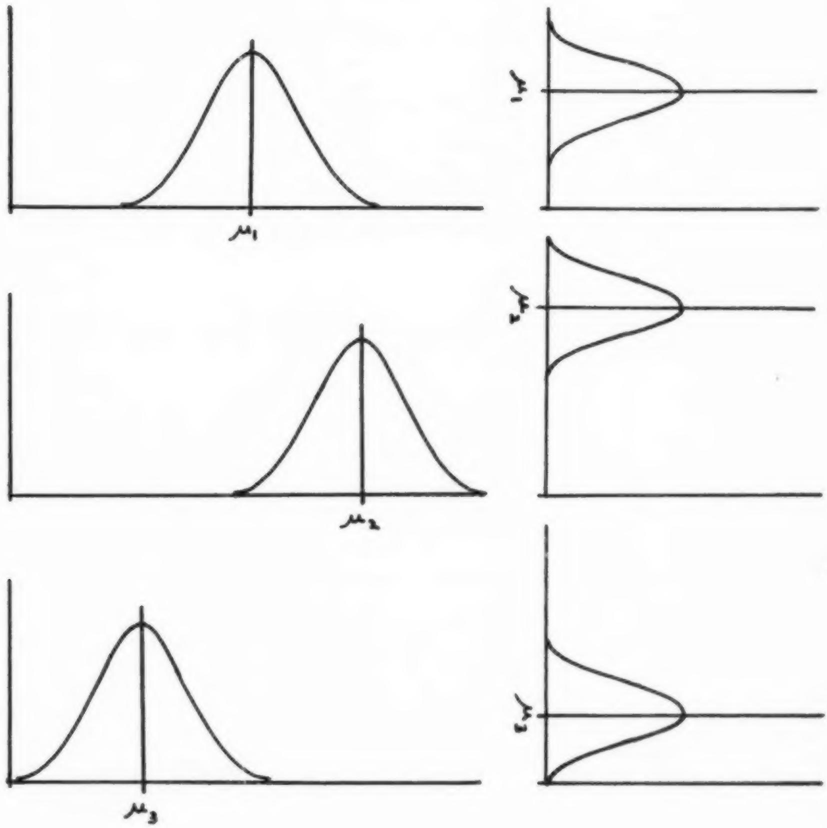
It remains true, however, that one must always make, for each quality characteristic, a serious effort to solve the problem of the validity of the statistical assumptions and the problem of comparative costs, as indicated above. Only if we are successful here can control limits be sensibly located. For those who have expectation of success the following remarks are intended to clarify the statistical consequences which follow from the fixing of control limits.

A Simple Control Chart and its Probability Aspects

Let us consider a simple and somewhat academic example but one which will reveal the statistical concepts involved in measuring the frequency of errors of both kinds. Let the quality characteristic be normally distributed with fixed and known standard deviation σ. Let the mean of the process be μ; the process will be described as in "perfect" control if $\mu = \mu_1$, and out of control if μ is sufficiently above or below μ_1. The facts stated so far can be illustrated by distribution curves or by lines and curves on control charts. In Figure 2 we use both.

Figure 2

Distribution Curves and Corresponding Lines and Curves on Control Charts for Various Process Means. In the Upper Pair, the Process is in "Perfect" Control; in the Remaining Pairs, the Process is out of Control

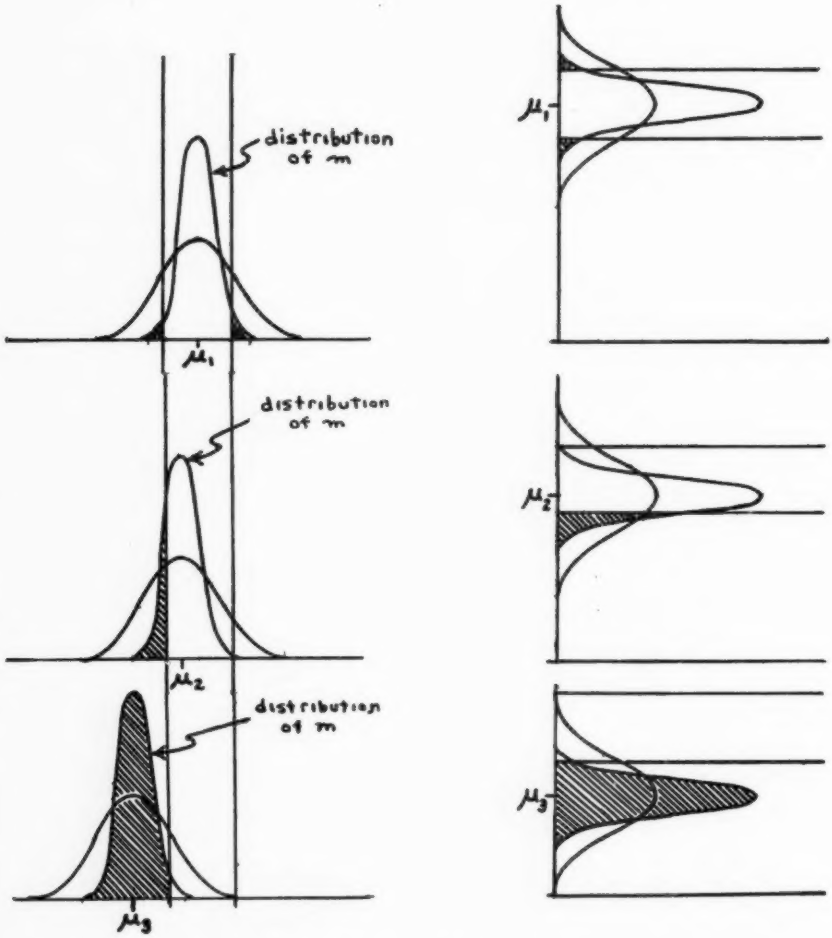


Now consider the probability problem associated with this situation for this is at the heart of the question of locating control limits. It is a three-fold problem. What function of the sample data and what rule on the behavior of the function serve best to detect changes in μ, and what is the probability distribution of this function? For a normal variable with known standard deviation σ, the function is the sample mean m, the rule is to declare the process out of control if m is greater than $\mu_1 + c$ or less than $\mu_1 - c$, where c is a constant;

finally, as is well known, the probability distribution of m is normal with standard error $\sigma/\sqrt{n}$. These remarks are illustrated in Figure 3.

Figure 3

Distribution of the Mean of a Sample from
Normal Populations of Standard Deviation σ and means μ_1, μ_2, and μ_3



On the diagrams in Figure 3, a pair of control limits have been drawn in; it is immediately evident that the frequency of errors of both kinds depends, at least in part, on the state of the process. In all diagrams in Figure 3 the frequency with which the sample mean lies

outside the control limits, that is, the frequency of taking action, is given by the shaded areas. When the process is in "perfect" control, as in the top pair of diagrams, these areas (the frequency of errors of the first kind) are small, which we regard as good. When the process is mildly out of control, as in the middle pair of diagrams, the frequency with which the sample mean lies <u>within</u> the control limits (the frequency of errors of the second kind) is large, which we regard as bad. Finally, when the process is considerably out of control, as in the bottom pair of diagrams, the frequency of errors of the second kind is very small, which we regard as good. Thus, even though we use the best statistical apparatus possible (the statistic m and the rule: take action if m lies outside $\mu_1 \pm c$) errors of inference cannot be avoided and for some values of μ their frequency is high. The particular choice of c in Figure 3 led to low frequency of errors of the first kind but to high frequency of errors of the second kind, except for values of μ departing greatly from μ_1. It is evident that another choice of c might lead to a preferable compromise, that is, to a compromise which would be, in the most general sense, more profitable.

The constant c is generally fixed as a multiple of the standard error of m, that is to say, $c = \pm 2\sigma_m$, $c = \pm 3\sigma_m$, etc. from which come the expressions "two-sigma limits," "three-sigma limits," and so forth.

Numerical Example

Let us now consider a numerical example. Let a process be in "perfect" control if its mean μ is 100#. Values of μ greater or less than 100# are undesirable and the further μ departs from 100#, the more unsatisfactory the process is. Assume that the quality characteristic is normally distributed with fixed standard deviation σ of 20#. Let us say that periodic random samples of size $n = 4$ are taken.

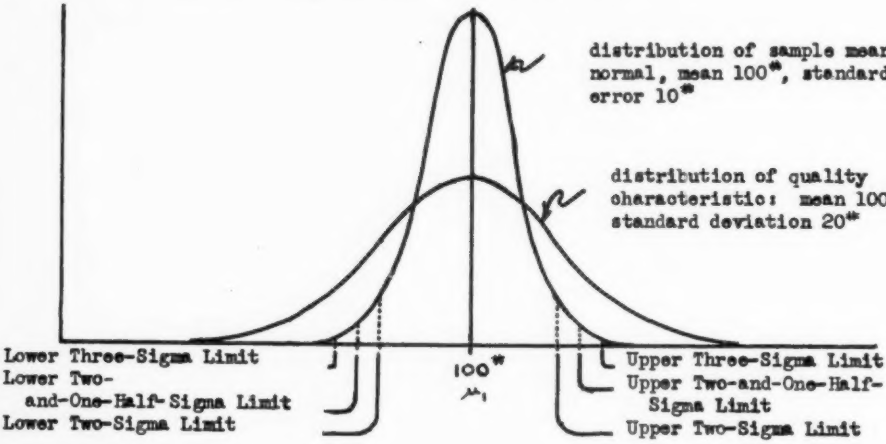
The two-sigma, two-and-one-half-sigma and three-sigma control limits would be placed at

$$100 \pm 2\,\frac{20}{\sqrt{4}}\,, \qquad 100 \pm 2.5\,\frac{20}{\sqrt{4}}\,, \qquad 100 \pm 3\,\frac{20}{\sqrt{4}}$$

respectively. These control limits are shown in Figure 4.

Figure 4

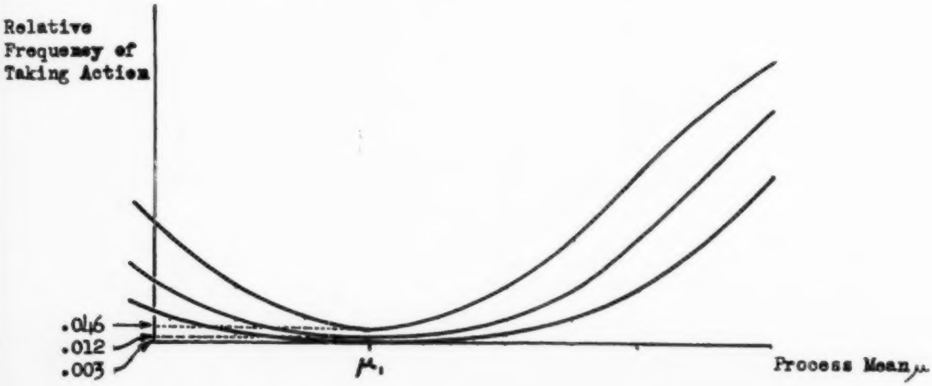
Two, Two-and-One-Half, and Three-Sigma Control Limits, Normally Distributed Quality Characteristic with Mean 100*, Standard Deviation 20*. Sample Size 4.



As we have seen, for this problem the frequencies of errors of the both kinds are immediately determined from tables of the normal distribution. If the process is in "perfect" control, the relative frequencies of taking action are favorably low, .046, .012, and .003, respectively. As μ departs from μ_1, the frequency of taking action increases, as it should. We can readily obtain the curves of Figure 5 from tables of the normal distribution.

Figure 5

Relative Frequency of Taking Action on Process, for various values of Process Mean, using Two, Two-and-One-Half, and Three Sigma Limits. Curves are Symmetrical about μ_1. The Sample Size is 4.



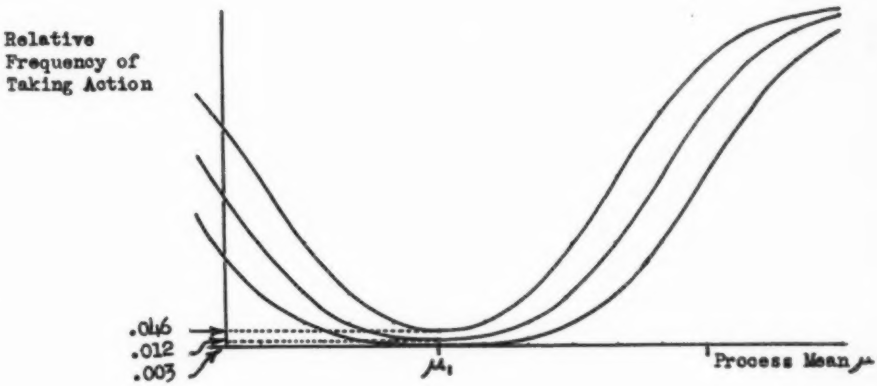
Which pair of control limits is best? We can only conclude that the choice must depend on the product, and in particular on the costs and prices associated with it. All three control limits shown above have found support in British and American industrial quality control practice, though it is occasionally difficult to say if the selection has been rational or imitative. Other values of c may of course be best in a particular situation.

<u>Effect of the Sample Size</u>

Note that one or both kinds of errors can be reduced, as would be expected, by increasing the sample size n. In Figure 6 curves for n = 9 are shown, using the same two-sigma, two-and-one-half sigma, and three-sigma limits as above. The frequency of taking action when the process is in perfect control is held constant but as μ changes, the relative frequency of taking action is higher than for the case n = 4. This is generally desirable but, of course, it is costlier.

Figure 6

Relative Frequency of Taking Action on Process, for various values of Process Mean, using Two, Two-and-One-Half, and Three Sigma Limits. Curves are Symmetrical about μ_1. The Sample Size is 9.



Other Examples

Those who are interested in these considerations and who would like to see how they apply to a more realistic quality control chart

should read the excellent article by Scheffé (1). The logic of Scheffé's examples is similar to that of the example discussed here, and the statistical complications of his more realistic situation are readily overcome. The extension of these methods of measuring frequency of error to strikingly non-normal quality characteristics is not easily effected, due to the general lack of tables of the distribution of sample functions from non-normal populations.

Reference

(1) Scheffé, Henry. "Operating Characteristics of Average and Range Charts," Industrial Quality Control, Vol. V, No. 6., May, 1949, pages 13-18.

QUICK AND DIRTY METHODS IN STATISTICS

PART II - SIMPLE ANALYSES FOR STANDARD DESIGNS*

John W. Tukey
Princeton University

1. Introduction

While I am proud to appear under the banner of "quick and dirty" methods, the reader who is unfamiliar with the term should be warned that it really means "quick and not so dirty". The methods to be set forth here are so effective that I believe that, possibly modified, they are going to become the routine methods of analyzing these sorts of data. The more complicated classical methods will then be saved for special circumstances.

For the present, we are going to discuss the analysis of the following sorts of experiments:

(i) Several groups of measurements, each group of the same size.

(ii) Rectangular arrays of measurements, where both rows and columns are meaningful.

(iii) Latin squares.

These experiments have classically been analyzed by the analysis of variance - we shall present shorter methods.

2. One-way classifications

As an example we choose Griffith, Westman and Lloyd's example (1) on gauging times in seconds. The observations and initial computations are:

Examiner	1	2	3	4	5	
Gauging Times	13	14	14	15	13	
	14	14	15	14	16	
	12	13	13	14	14	
	14	14	15	14	14	
Total	53	55	57	57	57	
Range	2	1	2	1	3	Sum of ranges = 9

We now enter Table 1 with the number of groups (= 5) and the number per group (= 4) and find the block of entries

0.85	0.58
1.08	0.80

If we multiply these numbers by the sum of ranges (= 9) we find

7.6	5.2
9.7	7.2

and have now to decide whether to accept 5% risk of error by using the upper line or to accept 1% risk of error by using the lower line. We shall take 5% and the upper line, which leaves us with 7.6 and 5.2. The significance to be attached to these numbers is the following:

*Prepared in connection with research sponsored by the Office of Naval Research

(i) If we arrange the group totals in algebraic order, any gap longer than 5.2 is to recognized as real - as dividing the groups into separate piles.

(ii) If the range of the group totals exceeds 7.6, then the existence of a difference or differences among groups is to be recognized as real.

(iii) The true difference between any two group totals is to be recognized as lying within $\pm$ 7.6 of that observed.

By doing this, we shall make one or more false recognitions in slightly more than 5 experiments out of 100. (If we had used the lower line, we would have restricted our false recognitions to slightly more than 1 experiment per hundred.)

In our example, we find no gaps, and no excessive range. Therefore we conclude that there need be no real differences between examiners. We can still use (iii) usefully, for example as follows:

Examiner Comparison	Diff. of Totals	Allowance (5%)	Limits (Totals)	Limits (Means)
(Ex.4)-(Ex.1)	4	$\pm$7.6	-3.6 to 11.6	-0.9 to 2.9
(Ex.2)-(Ex.1)	2	$\pm$7.6	-5.6 to 9.6	-1.4 to 2.4

Here the last column is found from the next to the last one by dividing by the number in a group. We may set limits for any or all comparisons.

A final example of this sort comes from Tippett's new book (5, p.106) and refers to warp breakage rates for individual warps. The observations and computations are:

Yarn	AL	AM	AH	BL	BM	BH
Rates	26	18	36	27	42	20
	30	21	21	14	26	21
	54	29	24	29	19	24
	25	17	18	19	16	17
	70	12	10	29	39	13
	52	18	43	31	28	15
	51	35	28	41	21	15
	26	30	15	20	39	16
	67	36	26	44	29	28
Totals	401	216	221	254	259	169
Ranges	45	24	33	30	26	41

Sum of ranges = 199

Table 1 gives

0.71	0.48
0.85	0.64

Product

141	96
169	127

Sample conclusions

(1) AL gives the highest breakage rate (1% risk based on gap).

(2) BM-AM has a true mean difference between -11 and +20 (5% risk based on range).

(3) All yarn except AL could be giving the same mean breakage rate.

3. Two-way classifications

In order to apply similar technique to data in a two-way classification, we must do a little subtraction before finding ranges. This is illustrated now on Grant Wernimont's example (7) of Thermometer and Analyst variability in determining the melting point of hydroquinone. The observations used here are the sums of the melting points found on 2 days.

Author's corrections to lower half of

	S
Range of column BH	
Sum of ranges	
Product	1
	1
Limits for BM-AM	-

f of Page 190

Should be	Printed as
15	41
173	199
123 83	141 96
147 111	169 127
-9 and +19	-11 and +20

J. W. Tukey

Thermometers

Analysts	A	B	C	D
I	347.5	346.5	344.0	347.0
II	346.0	345.0	343.0	343.0
III	347.5	347.0	346.0	345.0
Means	347.0	346.17	344.33	345.17

If we subtract the means by thermometer from the observations, we find

	A	B	C	D	Totals	Ranges
	0.5	0.33	-0.33	1.83	2.33	2.16
	-1.0	-1.17	-1.33	-2.17	-5.67	1.17
	0.5	0.83	1.67	0.33	3.33	1.34
Totals	0.0	-0.01	0.01	-0.01	-0.01	4.67

Now we enter Table 2A with the number of entries per mean (= 3) and the number of entries per range (= 4). We find a block of 8 entries as follows:

1.65	1.33	0.54	0.38
2.45	2.02	0.79	0.58

where the upper line is for 5% risk, the lower for 1% risk, while the columns are for (i) range of totals, (ii) gap of totals, (iii) range of means, (iv) gap of means, where the means are taken one way of the table and the totals are taken the other way after adjustment. Multiplying by the sum of ranges (after adjustment), 4.67, these become

7.7	6.2	2.5	1.8
11.4	9.4	3.7	2.7

We now compare the totals (for analysts) with the left hand block

III	3.33		7.7	6.2
I	2.33		11.4	9.4
II	-5.67			

just as before, concluding that Analyst II is different at 5% risk, and compare the means (for thermometers) with the right-hand block

A	347.00		2.5	1.8
B	346.17		3.7	2.7
C	345.17			
D	344.00			

in a similar way, concluding that they are different with a 5% risk. If we wish to set limits on thermometer differences, we omit the last step of the procedure based on totals, since we are already in terms of means. Thus (A) - (D) = 2.67 ± 2.5 and lies between 0.17 and 5.17 with 5% risk.

4. Latin squares

In this case we shall have to remove two sets of means. We start with another warp breakage example from Tippett (5, p. 123), where the three variables are serial number of warp, period of time, and number of loom. The observations (of warp breakage rate) and initial calculations are:

Serial Number of Warp

		426	427	428	429	
Period	1	5.52 (1)	2.87 (4)	9.76 (7)	6.69 (3)	(Loom numbers
of	2	6.02 (4)	6.25 (7)	5.14 (3)	9.16 (1)	in paren-
Time	3	8.90 (7)	2.91 (3)	5.77 (1)	6.53 (4)	theses)
	4	6.09 (3)	5.07 (1)	2.83 (4)	9.77 (7)	
Means		6.64	4.28	5.88	8.04	

Singly adjusted values

					Means
	-1.12 (1)	-1.41 (4)	3.88 (7)	-1.35 (3)	0.00
	-0.62 (4)	1.97 (7)	-0.72 (3)	1.12 (1)	0.44
	2.26 (7)	-1.37 (3)	-0.11 (1)	-1.51 (4)	-0.18
	-0.53 (3)	0.79 (1)	-3.05 (4)	1.73 (7)	-0.26
Totals	-0.01	-0.02	0.00	-0.01	0.00

Doubly adjusted values

-1.12 (1)	-1.41 (4)	3.88 (7)	-1.35 (3)
-1.06 (4)	1.53 (7)	-1.16 (3)	0.68 (1)
2.44 (7)	-1.19 (3)	0.07 (1)	-1.33 (4)
-0.27 (3)	1.05 (1)	-2.79 (4)	1.99 (7)

We can rearrange the doubly adjusted values to find:

	(1)	(3)	(4)	(7)
	-1.12	-1.35	-1.41	3.88
	0.68	-1.16	-1.06	1.53
	0.07	-1.19	-1.33	2.44
	1.05	-0.27	-2.79	1.99
Totals	0.68	-3.97	-6.59	9.84
Ranges	2.17	1.08	1.73	2.35

Sum of Ranges = 7.33

Table 3 gives

1.54	1.08	0.38	0.27
2.23	1.50	0.56	0.38

Product

11.29	7.92	2.8	2.0
16.35	11.00	4.1	2.8

Again the left-hand block of the tabular entry, found this time in Table 3, is to be used for totals, while the right-hand block is to be used for the means and adjusted means formed in the process of adjustment. If we adopt a 5% risk as out standard, we find the following:

<u>Among loom numbers</u>. The adjusted totals were 0.68, -3.97, -6.59, 9.84. Comparing with 7.92 we see that loom (7) is recognizably worse than the others. Comparing with 11.29 we see that the other looms could be alike. Apparent differences in loom totals are to be relied on to $\pm$ 11.29.

<u>Among time periods</u>. The adjusted means were 0.00, 0.44, -0.18, -0.26. Comparing with 2.0 we can establish no gaps. Comparing with 2.8 we are not forced to assume time periods different. Apparent differences in time period means are to be relied on to $\pm$2.8.

<u>Among warps</u>. The means were 6.64, 4.28, 5.88 and 8.04. Comparing with 2.0 we can establish no gaps. Comparing with 2.8 we can see that warp 427 is recognizably better than 429. Apparent differences in warp means are to be relied on to $\pm$2.8.

5. Background of tables

The tables which follow were computed on the basis of approximations which are almost certainly accurate enough for practical use. All the gap values are based on Lord's tables (3) and the philosophy of the use of such tables in combination with others has been discussed by Tukey (6). The range values are based on approximations resembling those of Patnaik (4) and Hartley (2), although differing in detail. An account of their computation will be published elsewhere. In particular, it should be noted that the range values of Tables 2 and 3 are deliberately conservative to a small extent, and definitive tables will be quite likely to contain slightly smaller values.

The actual computation has been directed by D.L. Wallace and R.F. Link, with the assistance of T.E. Kurtz, D.M. Wishart, and Miss M.A. Knaefler. The thanks of the user of the tables should go to this group.

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TABLE 1

CRITICAL FACTORS FOR ONE-WAY (BALANCED) DIVISIONS INTO GROUPS

The four entries are, respectively, for

Range with 5% risk Gap with 5% risk
Range with 1% risk Gap with 1% risk

and are to be multiplied by the sum of the ranges within groups. (Risks are on per experiment basis).

Number in group = Number per range

Number of groups = Number of ranges summed	2	3	4	5	6	7	8	9	10
2	3.43 3.43 7.92 7.92	1.91 1.91 3.14 3.14	1.63 1.63 2.47 2.47	1.53 1.53 2.24 2.24	1.50 1.50 2.14 2.14	1.49 1.49 2.10 2.10	1.49 1.49 2.08 2.08	1.50 1.50 2.09 2.09	1.52 1.52 2.09 2.09
3	2.37 1.76 4.42 3.25	1.44 1.14 2.14 1.73	1.25 1.02 1.74 1.47	1.19 0.98 1.60 1.37	1.18 0.96 1.55 1.32	1.17 0.96 1.53 1.33	1.17 0.97 1.52 1.33	1.18 0.98 1.53 1.34	1.20 0.99 1.55 1.36
4	1.98 1.18 2.96 1.96	1.13 0.81 1.57 1.19	1.01 0.74 1.33 1.04	0.94 0.72 1.24 0.98	0.92 0.71 1.21 0.96	0.92 0.71 1.21 0.96	0.94 0.72 1.21 0.97	0.96 0.73 1.22 0.98	0.97 0.74 1.23 0.99
5	1.40 0.88 2.06 1.39	0.94 0.63 1.25 0.91	0.85 0.58 1.08 0.80	0.81 0.56 1.02 0.77	0.80 0.56 0.99 0.76	0.80 0.56 0.99 0.76	0.81 0.57 0.99 0.77	0.82 0.58 1.00 0.77	0.84 0.59 1.01 0.78
6	1.16 0.70 1.69 1.07	0.81 0.52 1.04 0.73	0.75 0.48 0.94 0.66	0.69 0.47 0.86 0.63	0.69 0.46 0.85 0.62	0.69 0.47 0.85 0.63	0.70 0.47 0.85 0.63	0.71 0.48 0.85 0.64	0.72 0.49 0.86 0.65
7	1.00 0.58 1.39 0.87	0.70 0.44 0.89 0.61	0.63 0.40 0.78 0.55	0.61 0.40 0.75 0.54	0.61 0.40 0.74 0.53	0.61 0.40 0.74 0.53	0.62 0.41 0.74 0.54	0.63 0.41 0.75 0.55	0.63 0.42 0.76 0.55
8	0.87 0.50 1.20 0.74	0.62 0.38 0.78 0.53	0.57 0.35 0.69 0.48	0.55 0.34 0.66 0.47	0.55 0.34 0.65 0.46	0.55 0.35 0.65 0.46	0.55 0.35 0.66 0.47	0.56 0.36 0.66 0.48	0.57 0.37 0.67 0.48
9	0.78 0.44 1.03 0.63	0.56 0.33 0.71 0.46	0.51 0.31 0.62 0.44	0.50 0.30 0.59 0.43	0.49 0.30 0.59 0.42	0.50 0.31 0.59 0.42	0.50 0.31 0.59 0.42	0.51 0.31 0.60 0.43	0.52 0.32 0.61 0.43
10	0.70 0.39 0.91 0.56	0.51 0.30 0.62 0.41	0.46 0.28 0.57 0.38	0.45 0.27 0.54 0.37	0.45 0.27 0.53 0.36	0.45 0.28 0.54 0.37	0.46 0.28 0.54 0.37	0.47 0.28 0.55 0.38	0.47 0.29 0.55 0.38

TABLE 2 A(2 TO 6 ENTRIES PER MEAN)

CRITICAL FACTORS FOR TWO-WAY DIVISION INTO GROUPS

The eight entries are for, respectively,

Adjusted totals		Means used to adjust	
Range at 5% risk	Gap at 5% risk	Range at 5% risk	Gap at 5% risk
Range at 1% risk	Gap at 1% risk	Range at 1% risk	Gap at 1% risk

and are to be multiplied by the sum of the ranges of adjusted values.
(Risks are on a per type of category basis.)

Number of entries per mean = number of ranges = number of totals

Number per range = number per total = number of means	2		3		4		5		6	
2	12.7 12.7 63.6 63.6	6.36 6.36 31.8 31.8	3.97 2.80 9.94 6.46	1.14 1.14 2.64 2.64	2.25 1.52 4.63 2.81	0.54 0.54 0.99 0.99	1.74 1.06 2.82 1.76	0.33 0.33 0.55 0.55	1.36 0.81 1.99 1.27	0.23 0.23 0.37 0.37
3	3.91 3.91 9.02 9.02	2.18 1.60 5.02 3.68	2.00 1.56 3.23 2.56	0.67 0.52 1.08 0.85	1.41 0.99 2.06 1.50	0.36 0.29 0.54 0.43	1.10 0.73 1.50 1.07	0.23 0.19 0.33 0.28	0.90 0.58 1.20 0.83	0.17 0.14 0.23 0.20
4	2.87 2.87 5.27 5.27	1.50 1.01 2.60 1.86	1.65 1.33 2.45 2.02	0.54 0.38 0.79 0.58	1.21 0.88 1.65 1.27	0.30 0.22 0.41 0.32	0.97 0.66 1.26 0.93	0.20 0.15 0.27 0.21	0.82 0.53 1.14 0.73	0.15 0.11 0.19 0.15
5	2.53 2.53 4.21 4.21	1.29 0.80 2.09 1.33	1.54 1.25 2.19 1.83	0.47 0.32 0.67 0.47	1.14 0.84 1.50 1.19	0.28 0.19 0.36 0.27	0.92 0.64 1.18 0.88	0.18 0.13 0.24 0.18	0.78 0.51 0.97 0.70	0.14 0.094 0.17 0.13
6	2.40 2.40 3.77 3.77	1.16 0.69 1.74 1.09	1.50 1.22 1.98 1.75	0.45 0.29 0.59 0.41	1.13 0.83 1.45 1.16	0.26 0.17 0.33 0.24	0.88 0.63 1.14 0.87	0.17 0.12 0.22 0.16	0.77 0.51 0.94 0.69	0.13 0.085 0.16 0.12
7	2.33 2.33 3.55 3.55	1.08 0.62 1.54 0.95	1.47 1.22 1.96 1.71	0.43 0.27 0.55 0.37	1.12 0.83 1.43 1.15	0.25 0.16 0.31 0.22	0.88 0.63 1.14 0.86	0.17 0.11 0.21 0.15	0.77 0.51 0.94 0.69	0.12 0.079 0.15 0.11
8	2.30 2.30 3.43 3.43	1.00 0.58 1.40 0.86	1.47 1.22 1.96 1.70	0.41 0.25 0.52 0.35	1.12 0.84 1.42 1.15	0.24 0.15 0.30 0.20	0.90 0.64 1.14 0.87	0.16 0.10 0.20 0.14	0.78 0.52 0.94 0.70	0.12 0.075 0.14 0.10
9	2.29 2.29 3.36 3.36	0.97 0.54 1.32 0.79	1.48 1.23 1.96 1.70	0.40 0.24 0.50 0.33	1.13 0.85 1.43 1.16	0.23 0.14 0.28 0.19	0.91 0.65 1.15 0.88	0.16 0.097 0.19 0.13	0.79 0.53 0.95 0.71	0.12 0.072 0.14 0.096
10	2.30 2.30 3.33 3.33	0.93 0.51 1.24 0.74	1.49 1.24 1.96 1.71	0.39 0.23 0.48 0.31	1.15 0.86 1.44 1.17	0.23 0.14 0.28 0.18	0.92 0.66 1.16 0.88	0.16 0.093 0.19 0.12	0.80 0.53 0.96 0.71	0.12 0.069 0.14 0.092

TABLE 2 B(7 TO 10 ENTRIES PER MEAN)

CRITICAL FACTORS FOR TWO-WAY DIVISION INTO GROUPS

The eight entries are for, respectively,

Adjusted totals		Means used to adjust	
Range at 5% risk	Gap at 5% risk	Range at 5% risk	Gap at 5% risk
Range at 1% risk	Gap at 1% risk	Range at 1% risk	Gap at 1% risk

and are to be multiplied by the sum of the ranges of adjusted values. (Risks are on a per type of category basis.)

Number of entries per mean = number of ranges = number of totals

Number per range = number per total = number of means	7		8		9		10	
2	1.13 0.65 1.63 1.00	0.17 0.17 0.27 0.27	0.97 0.55 1.35 0.82	0.14 0.14 0.20 0.20	0.84 0.47 1.16 0.69	0.11 0.11 0.16 0.16	0.76 0.42 1.00 0.60	0.093 0.093 0.13 0.13
3	0.78 0.48 1.00 0.68	0.13 0.10 0.17 0.15	0.68 0.41 0.86 0.57	0.10 0.083 0.14 0.12	0.60 0.36 0.75 0.50	0.083 0.069 0.11 0.095	0.54 0.32 0.69 0.44	0.071 0.058 0.092 0.080
4	0.72 0.44 0.90 0.61	0.11 0.083 0.14 0.11	0.61 0.38 0.75 0.52	0.086 0.067 0.11 0.092	0.57 0.33 0.66 0.45	0.073 0.055 0.093 0.075	0.49 0.30 0.60 0.40	0.062 0.047 0.078 0.063
5	0.66 0.43 0.82 0.59	0.10 0.073 0.13 0.099	0.59 0.37 0.72 0.50	0.083 0.059 0.10 0.079	0.56 0.33 0.63 0.44	0.069 0.048 0.084 0.065	0.49 0.29 0.57 0.39	0.058 0.041 0.071 0.055
6	0.66 0.43 0.81 0.58	0.098 0.066 0.12 0.089	0.59 0.37 0.71 0.50	0.079 0.053 0.10 0.072	0.53 0.32 0.62 0.43	0.066 0.044 0.079 0.059	0.47 0.29 0.57 0.39	0.055 0.037 0.067 0.050
7	0.67 0.43 0.81 0.58	0.096 0.062 0.11 0.083	0.59 0.37 0.71 0.50	0.076 0.050 0.092 0.067	0.53 0.33 0.62 0.44	0.063 0.041 0.076 0.055	0.48 0.29 0.57 0.39	0.053 0.035 0.064 0.047
8	0.67 0.44 0.81 0.59	0.093 0.058 0.11 0.078	0.59 0.38 0.71 0.50	0.074 0.047 0.089 0.063	0.53 0.33 0.63 0.44	0.061 0.039 0.073 0.052	0.48 0.30 0.57 0.39	0.052 0.033 0.062 0.044
9	0.68 0.44 0.81 0.59	0.090 0.056 0.11 0.074	0.61 0.38 0.72 0.51	0.073 0.045 0.086 0.060	0.54 0.34 0.63 0.45	0.060 0.037 0.071 0.050	0.49 0.30 0.58 0.40	0.051 0.032 0.060 0.042
10	0.69 0.45 0.82 0.60	0.089 0.054 0.10 0.072	0.61 0.39 0.73 0.52	0.071 0.043 0.084 0.058	0.55 0.34 0.64 0.45	0.059 0.036 0.069 0.048	0.50 0.30 0.59 0.40	0.050 0.030 0.058 0.040

TABLE 3

CRITICAL FACTORS FOR LATIN SQUARES

The eight entries are for, respectively,

Range for 5% risk Gap for 5% risk Range for 5% risk Gap for 5% risk
Range for 1% risk Gap for 1% risk Range for 1% risk Gap for 1% risk

and are to be multiplied by the sum of the doubly adjusted ranges.

Side of Square	Entries			
3	3.78	2.76	1.26	0.92
	8.70	6.37	2.90	2.12
4	1.54	1.08	0.38	0.27
	2.23	1.50	0.56	0.38
5	1.07	0.73	0.21	0.15
	1.40	1.03	0.28	0.21
6	0.85	0.56	0.14	0.094
	1.07	0.70	0.18	0.12
7	0.73	0.47	0.10	0.067
	0.88	0.64	0.13	0.091
8	0.64	0.40	0.080	0.050
	0.76	0.54	0.095	0.068
9	0.58	0.36	0.064	0.040
	0.68	0.48	0.076	0.053
10	0.53	0.32	0.053	0.032
	0.62	0.42	0.062	0.042

INSTALLING A QUALITY CONTROL SYSTEM

by J. M. Juran
Author, Lecturer and Consultant in Management

Because the words Quality Control mean many things to many people, it is useful at the outset to define terms. Most managers of my acquaintance would agree with me if I defined Quality Control as the means for achieving defect prevention. Such is the meaning I will give to the term in this paper.

My first point is that <u>the tools for defect prevention are numerous and varied</u>.

The causes of defects are widely varied. Thereby the means for prevention must be correspondingly varied. Let me list a few of these causes and the corresponding cures so that we may see in perspective this collection of preventive means.

Within the orbit of the machine operator we recognize that four requirements must be met simultaneously. We can tabulate these requirements and the means for meeting them:

Requirement	Means for Meeting the Requirement
The operator must know what he is supposed to be doing; i.e., he must know the specification for the product or process.	Disclosure of this information to the operator, through publication, through training, etc.
The operator must know what he *is* doing; i.e., he must *have* means for knowing whether or not he is meeting specifications.	Provision of adequate standards, gages and instruments, plus training in their use.
The operator must have means for regulating the process in the event of failure to meet specification.	Provision of adequate adjustments in the machine or process. Training in use of these.
The operator must have the determination to use all these means to produce conforming product.	Provision of adequate incentives; launching a campaign to increase quality-mindedness.

So far, in talking only about the problems of the production operator, we have already listed, as tools for defect prevention, good employee communication, good training, development of quality standards, improved instrumentation, im-

proved machine design and process engineering, improved incentives, and a campaign for improving quality-mindedness. (This last is itself a whole collection of tools.)

The foregoing list requires contributions from the personnel specialist, the inspection supervisor, the instrument designer, the machine designer, the process engineer, the industrial engineer and still others. Several branches of engineering, and several branches of the social sciences are already involved.

A great many causes for defects are simply unknown. A usual symptom here is that each man points to someone else as being responsible for the defects. The cure for such cases is to collect new and essential data, to analyze them and to present the findings in a way which stimulates action. We may here add to our tabulation:

Requirement	Means for Meeting the Requirement
To collect the new essential data.	Standards and instruments. Design of experiments. Organization (to provide a trained fact finder).
To analyze the data.	Statistical know-how
To secure action on the facts.	Statistical summary and graphic presentation. Salesmanship to sell the conclusions.

We can now add, to the preceding list of means, the tools of statistics, organization and salesmanship.

Nor is this all. Before much concerted effort can be brought to bear on the problem of defects, there must be a sale to top management on the merits of such a concerted effort. This increases our tabulation as follows:

Requirement	Means for Meeting the Requirement
Determination of the total cost of avoidable defects.	Analysis of accounting reports; analysis of inspection reports.
Preparation of a budget for a defect prevention program.	Accounting and engineering analysis.
Development of an organization plan to launch and sustain a program.	Organization planning.

Development of targets for defect reduction for various departments.	Accounting, inspection and engineering analysis.
Development of executive reports for executive control.	The "executive instrument panel".

To our list of means we have added accounting, budgeting, organization planning, executive reporting, and some additional specialties of engineering.

Nor is this all. We have made no mention of market analysis to see what are the competitors doing; of consumer research to study consumer preferences and consumer ability to discriminate. We have made no mention of complaint analysis, or of relating field service data to design and manufacturing data.

The foregoing should make clear that defect prevention requires a wide variety of tools because defects have a wide variety of causes.

I now return to the subject "Installing a Quality Control System" which under my definition becomes "Installing a Defect Prevention System". It is clear that there is a wide assortment of tools necessary to constitute a "system" for defect prevention. It should be equally clear that emphasis on but one set of tools such as the tools of machine design, or instrument design, or statistical methods, or accounting analysis, runs a serious risk of failure because the causes of defects are too numerous and complex to be solved by any one set of tools.

My second point is that <u>so wide a variety of tools requires the participation of numerous departments in the company</u>.

The accounting department determines the cost of defects, prepares a budget for a defect prevention program, and keeps the score on how the program progresses. The sales department is involved in analysis of customer complaints, in market research and in consumer research. The product designers are involved in establishment of engineering tolerances and standards. The personnel department is involved in training, in communications and in any program for quality-mindedness. The process engineers are involved in machine design, process development, and instrument design. The inspection department is involved in the setting of standards and in collection of data. The production supervisors are involved in training, in stimulating operators, and in detailed corrective action. The industrial engineers are involved in organization planning and in wage incentives. The

quality control engineers are involved in engineering and statistical analysis. Top management is involved in coordination and in executive controls.

This is a formidable list of organizations. Yet they are all there. Any omission not only deprives the program of the potential aid of departments who have a contribution to make; it risks the opposition of such omitted departments.

My third point is that collaboration among numerous departments requires a plan.

It hardly requires elaboration to point out that so broad a list of departments can best work together only if there exists a well thought out plan on how they can and should work together.

In a recent paper[1] I reported on the results of quality control programs started since World War II by 39 companies. That study disclosed a shocking mortality rate for these programs. The failures were largely due to failure to utilize the managerial tools for defect prevention while at the same time over-emphasizing the statistical tools. It is primarily for the heads of quality control departments to avoid such failures by expanding their own horizon to include all tools for defect prevention, not just the statistical tools.

(I might note, in passing, that recognition of this very point is going to be decisive on the success or failure of the American Society for Quality Control as well. The Society must debate this issue to determine whether it will become a forum for development of all tools for quality control or whether it will confine itself only to the statistical tools for quality control.)

The more nearly the actual program includes the following list of steps, the greater is the probability of success:

1. Compute the "gold in the mine" - how much less it would cost to operate if there were no defects, no failures to meet specification.

2. Estimate how much of this is avoidable. If the company has never gone into a modern quality control program, you are pretty safe in assuming that half the "gold in the mine" can economically be saved. This estimate of avoidable loss is a cardinal figure. The extent of avoidable loss automatically decides whether a program is needed at all, how big the program should be, and what should be the time table.

3. Determine how the avoidable loss is distributed among departments, products, processes, etc. This distribution is necessary to establish the order of priority for study and to establish the improvement quotas.

4. Determine how the avoidable loss is divided as to responsibility, whether operator responsibility, non-operator responsibility, or unknown responsibility. This division indicates the proper emphasis of the program as between a campaign for quality-mindedness vs. a campaign for fact finding.

5. Establish a steering committee or other organizational device for securing participation of all interested departments in putting the program into effect.

Give this committee responsibility for:

(a) Identifying what are the major quality problems of the company.

(b) Considering possible improvements in handling these major problems.

(c) Recommending solutions.

(d) Observing and following progress made in solution.

6. Estimate the budget needed for fact finding (quality control engineers), for putting on a campaign for quality-mindedness, for score-keeping and for other necessary activities as developed by the steering group.

7. Set up a plan of action for all departments, including a set of quotas for improvement, and a time table for securing the improvements.

8. Organize or expand a quality control department to a size appropriate for the extent of avoidable loss. At present (1951) a usual ratio is one quality control engineer for each 500 production operators.

9. Set up a system of score-keeping on avoidable loss to enable non-supervisors, supervisors and executives to follow the progress of the program.

10. Set up appropriate training programs for supervisors and other key personnel. Her again do not make the mistake of restricting the training) use of only a few specialized tools.

11. If there is need for a campaign for better quality-mindedness, a special series of steps is involved. The purpose of these steps is:

(a) To demonstrate to each operator how the company's quality is important to him, personally.

(b) To show him how he can personally make a contribution to better quality at lower cost.

(c) To stimulate him to make that contribution.

To achieve all this requires special means including:

(a) Contests for slogans, for quality improvements, and for suggestions.

(b) Posters, articles in the house organs, displays of good and bad work, and other means for communication to employees.

(c) Special training material to stimulate operator interest, to show how to tell good work from bad, and how to prevent defects from happening.

(d) Measure of operator quality to discover and reward the successful operators, and to discover and train the unsuccessful operators.

My final point is that the Quality Control Department must concern itself primarily with the overall plan, and only secondarily with the special tools in which it is skilled.

The prime job of the quality control department is to develop an overall program for defect prevention, to define the role of each department in that program, to coordinate these various efforts, and to measure and report the results.

A secondary job of the quality control department is to contribute to this overall effort those special tools in which it has special skills, the tools of engineering and statistical analysis.

At the risk of over-simplification, may I assert that to date, the quality control departments have largely devoted themselves to their secondary job while neglecting their primary job. Thereby many programs have failed or stalled.

In making this assertion I am not attempting to lay blame-I am attempting merely to be realistic. There is no "blame". It takes good industrial experience and particularly a breadth of managerial experience to see the broad perspective of industrial operation. Most of the men selected to

date to head quality control programs have had prior technical and statistical experience rather than managerial experience. Under the circumstances, those who rose to the occasion have shown remarkable adaptability, since they had to be virtually self-teaching in perspective, and that in a short time.

Conclusion

The prime (though not the sole) purpose of quality control, as interpreted by industrial executives, is to prevent defects from happening.

Defect prevention requires use of numerous tools in the natural and social sciences. Skill in the use of these numerous tools is scattered among various departments of the industrial company. Maximum effectiveness of the defect prevention program is achieved only when there is a definition and a coordination of the roles of all of these various departments.

In many companies there have been established quality control departments for the prime purpose of defect prevention. In the view of the executives, it is the prime mission of these quality control departments to marshall all of the companies' various skills for defect prevention into one unified program.

Many quality control departments have missed the point here. The reason lies in the fact that these quality control departments are themselves skilled in use of the special tools of engineering and statistical analysis. Possessing these special tools and skills, they have concentrated on promotion of those tools and skills. But they have done this to the neglect of the broader and more important problem of generating an overall program in which all departments can participate.

The record in companies which have emphasized the broad program is one of comparative successes. In sharp contrast is the record of comparative failures in companies which have emphasized use of a limited few tools.

The contrast in performance suggests also the need for a re-appraisal of the job of the quality control department. Quality Control engineers and particularly the heads of quality control departments must widen their perspective drastically. They must regard their prime job as the harnessing of all skills which can aid in defect prevention, wherever those skills may be found in the various departments of the company. They must resist any temptation to consider their personal skills as the hub of the program.

The available records indicate that the more this temptation is resisted, the greater is the probability that the program will succeed.

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INSTALLING STATISTICAL QUALITY CONTROL IN A PHARMACEUTICAL MANUFACTURING COMPANY

John K. Taggart
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I am very happy to have this opportunity to discuss some aspects of installing a statistical quality control department with you. Many excellent papers have been published on this subject. I think, however, that a verbal presentation in which the opportunity for questions exists also serves a purpose. This afternoon I would like to present for your consideration a non-technical story of the experiences we have had in the installation of a financially successful statistical quality control department.

I have been graciously presented to you by Mr. Wescott, but now I would like to know something of our audience. May I have a showing of hands on the following points.

1. Those who are associated with the pharmaceutical or chemical industry

2. Those who have a well-established and operating statistical quality control department

3. Those who are contemplating installing a statistical quality control department in the near future or who have just initiated such a program.

Experience has shown that at least some degree of success of a statistical quality control department is dependent upon the way in which it is introduced and installed. It has been said that we learn from the mistakes of others, but I do not necessarily agree with this theory. I believe it is more nearly true that we learn from the experiences others have had. We undoubtedly have made mistakes in our installation and operation of statistical quality control, but I believe that they were mistakes of omission rather than commission.

Fortunately, most of us are participants in a system of private enterprise whose success depends upon competition and profits. Based on the returns we have realized from the utilization of these techniques, we are a financial success. Last year our savings in materials alone, based on our own bulk manufacturing costs, amounted to more than five times the cost of operating the statistical quality control department. I should also like to point out this important point relative to these savings which will apply as well in your own plant. Initially, you will be required to invest some risk capital in setting up the department, but whatever savings are realized will continue to accrue to your operation so long as you continue the installation. I would not have you believe that this is the only criterion on which your efforts in this field should be justified, but in my opinion it had better be during the early part of your program.

Perhaps you may find our history in statistical quality control of interest. I attended one of the 10-day courses which was presented at the Rochester Institute of Technology in the spring of 1947 and met

several men who previous to that time and since have contributed greatly to quality control in general and especially in the chemical and pharmaceutical fields. Dr. M. A. Brumbaugh and Mr. R. H. Noel, Bristol Laboratories, Inc., Mr. A. L. Davis, Rochester Institute of Technology, and Dr. Grant Wernimont, Eastman Kodak Company, to name but a few, all of whom were active in the presentation of that course. I am naming these men not merely to honor them, although no praise could be too great, but to bring up an important point. It may not be readily apparent during the installation of your own statistical quality control function or the daily direction of it, but eventually you will realize that your contacts with men well-versed and experienced in this field have been of great value to you. In this same vein, membership in the national society and attendance and participation in your local section's affairs are of even more importance. In other words, your association with men interested in the same fields will not only give you a lead to solving some of your technical problems but will build your own enthusiasm and make you better prepared to explain your program and aims to your in-plant associates.

In 1948 we were plagued by a problem which was common to the entire pharmaceutical industry and had been for some time previously - namely, the control of weights in vials of antibiotics. On a few occasions we had to empty-up and reprocess entire batches after they were filled into vials because we found low weights in our subsequent routine testing. This seemed to be an ideal occasion and the conditions just right for the application of statistical quality control. Initially, we put an individual in the filling area with instructions to randomly take samples from each operator and combine the results in a histogram. Since our problem was variation in weight, we used an analytical balance which gave us very accurate results, and an immediate improvement was apparent. Incidentally, the distribution we gave to these histograms was rather extensive and focused the attention of many interested people on our progress. We later restricted this distribution to those people who had an actual need for the information.

To those of you who have had even a limited experience in quality control work, the following is old hat. One of the basic characteristics of every individual is his pride in doing a good job. Since we have installed a control chart for each operator in the antibiotics filling department, we have made it possible for those individuals to develop a greater interest in their work than they had previously. One effect of this program is a smoother operating and more efficient department. Another and perhaps more valuable result is the job satisfaction enjoyed by the people who work there.

Fortunately, we had employed in our company Mr. Ralph Ernsberger who had an excellent academic background in chemical engineering and widely diversified experience in production and who was willing to accept the responsibility for installing statistical quality control in our plant even though at that time he was completely unfamiliar with statistical quality control. We made the necessary arrangements, and Mr. Ernsberger attended several courses at Purdue University where he received his instructions from Dr. Irving Burr whom many of you undoubtedly know personally. I am proud to publicly acknowledge the perseverence and industriousness Mr. Ernsberger displayed in commuting 120 miles to West Lafayette three times a week to take these courses and at the same time

to dispatch the duties of his previous job in our organization. In July, 1949, after he had completed these courses, we set up our statistical inspection department.

You may say, and rightly so, that we were not using statistical quality control, but we had made a start and that was important. Charts even with specification lines on them are merely pictures of an operation, but the value of statistical quality control will not be realized until your upper and lower statistical limits and also the limits for ranges in the X and R chart are on them. By knowing your processes, using the available "know-how", studying the control chart when you go out of control, and finding the assignable cause and correcting it is often surprisingly easy. Here I would like to make another important point. Go slowly. Our experience in this respect has been requests for expansion faster than we have been able to train people sufficiently for them to assume the responsibility for operating in statistical quality control jobs.

I know you have heard this statement made many times before, but I would like to emphasize it by reiteration. If you have a function in your operations which is costing your company excessively in materials, reject losses, or man hours, and can reproduce your measurements, then that is the area in which to start. This point of being able to reproduce your measurements is very important, and you should be able to verify them by repetition. It could prove rather embarrassing to discover that it was the variation in measurement and not the variation in the process that was causing the difficulty.

When you have selected the area in which you wish to start, the first thing to do is to go in and measure what the process is doing at that particular time. By all means, keep that data filed for future reference in order that you can publish subsequent reports on your progress. This is also important in each additional area when you enter it. You will need the backing of your company in order to establish the level of your jobs, and the only way you can gain backing is by an appraisal by management of your accomplishments.

Statistical quality control connotes measurements, and therefore it is a natural thing to have these results at hand, and do not be afraid to let your associates know of your progress. Keep your reports as concise as possible using only as much of your data as is essential in giving a clear picture. If someone who is a stickler for details questions your reasoning, you have an excellent opportunity for a selling job.

Historically, the pharmaceutical industry has been control-conscious, because not only can a drug be a life-saving product, but by improper compounding, mixed identity, variations in strength, insufficient testing, or improper use, it can also be a life-taking product. The first U.S.P. was published in 1820, the first National Formulary in 1888, and both have had interim revisions approximately every 10 years since. Supplementary revisions are made as required. The Pure Food and Drug Act was passed in 1906 and strengthened by additional regulations in 1938. I should like to point out that these official regulations originated within the industry itself.

Now that statistical quality control has demonstrated its value as a control medium, it has been accepted and will remain a permanent part of this vital industry.

Another of the salient points I would like to call to your attention depends somewhat on where in your line organization you place statistical quality control and the size of your plant. Remember, of course, again I am only speaking of our own experience, but I would ask you to give it serious consideration. The person to whom you give the responsibility for installing statistical quality control should have none of his time taken for other functions nor should he report directly to anyone who is responsible for meeting time schedules or production quotas. As nearly as possible, he should be a disinterested person whose sole function is fact finding.

The line supervision in our company is headed by the president to whom the executive vice-president reports and to whom in turn six functional vice-presidents report. These men are responsible for the following functions - finance, personnel, engineering, production, sales, and research and control. Division directors, one of whom in the research and control function is responsible for the control division, report directly to the vice-presidents. One of the operations reporting to the director of the control division is inspection for which, as manager of the inspection departments, I am responsible. We have four departments in the inspection group one of which is responsible for maintaining identity and quality standards on the packaging lines. Another is responsible for the identity and pharmaceutical elegance of our bulk manufactured goods. Another is responsible for the maintenance and accuracy of our measuring and controlling instruments. The fourth group is statistical quality control. Thus, you can see that the people responsible for quality do not report to people who are responsible for production, sales, or engineering. I am not suggesting this same organizational set-up will work in your plant, but it has worked out very well at least for us.

The Military Procurement Agencies requested the Stanford Research Institute to make a study of the agencies procurement policies and to submit their recommendations. This study was completed and a final report made in 1949. One of the recommendations in this report was that the agencies should encourage contractors to place their own in-plant inspection in their organization, so that it could function independently of the engineering and production functions.

Since we made our initial installation in 1949, we have developed and expanded the department until at the present time it is comprised of fourteen people. We have been fortunate in earning the confidence of our management in the value of our program. This has made it possible to establish a good rating for our jobs and to be able to attract a select group of employees to them. We have one job rated as "statistical inspector" which we have filled with men who have a collegiate background and who are interested in learning the advanced techniques of statistical quality control. The other job is rated as "statistical technician" and is mainly a routine sampling and measuring job. We have been fortunate in obtaining the services of a lady, who graduated from Purdue University in statistical quality control, serving as a clerk analyst in our office. I am pleased to report that we already

have had three "statistical inspectors" and one "statistical technician" transferred to other and more responsible jobs in the plant. I think this illustrates another value which you can derive from your statistical control department. Employees from many departments of your company will be better equipped to discharge their duties if they have had even a modest introduction of statistical techniques and thinking. All of us can benefit by having more people, especially in engineering and production functions, who think in terms of probability and variation control.

In Indianapolis, we have been unusually fortunate in opportunities for training in the techniques of statistical quality control. The Indianapolis section has conducted and is presently conducting classes taught by members of the section. Beginning with the present semester, Butler University, which is located in Indianapolis, has added a class in statistical quality control to its night business administration curriculum. This class is being taught by Mr. Ernsberger and is a college credit course.

Another of the important points essential to the success of your program will be the cooperation which you give to operating departments. At least a part of this success will depend on the collaboration you get in working out your mutual problems. We have tried on all occasions to lean over backwards in working with the groups where we were installing or making studies involving statistical quality control, and our reports invariably contain the statement, "With the aid and cooperation of the group in question, we have produced the stated results."

While the control we exercise in filling and manufacturing departments has been a large part of our operations in the past and will continue to be in the future, I would not have you believe that this is our only contribution to the company's operations. Another phase which is perhaps as valuable, and to me more interesting, is the work we have done in collaboration with the engineering function in the establishment of and degree of compliance with specifications in mechanical devices. We also have used these techniques in determining the acceptability of equipment. Another use is to determine the effects of adjustments or even redesign on some of our equipment by statistically analyzing the data taken from subsequent operation.

The merchandise development and control department in our plant is responsible for specifications and for receipt of packaging materials. Through one of the previously-mentioned transfers, we are assisting this department in establishing better relations with our vendors. In several instances we have assisted our vendors in establishing their own statistical quality control function, and as a result our packaging material is more uniform and therefore better.

So long as the identity as well as the quality of the product is a part of our inspection, we will continue at least 100% inspection on our finishing lines. However, if at some future date it is possible to separate quality from identity inspection, we will be able to sample for quality attributes and reap the rewards of statistical quality control in that area.

At the risk of belaboring the subject, I will list briefly the points again which I feel have been important in the installation and operation of statistical quality control in our plant. These may not all be equally important in your plant, but I feel you would do well to consider them.

1. The program must carry its financial weight.

2. Select the proper area in which to begin.

3. Be sure of the measurements.

4. Become active in the national and local activities of the American Society For Quality Control.

5. Go slowly.

6. Keep complete records.

7. Keep the reports concise.

8. Cooperate with operating and engineering functions.

9. Relieve the man who is responsible for statistical quality control of all other responsibilities.

10. Most important - Select the right man for the job.

These, I believe, have been the salient points in our program, and I trust that they may be of some benefit to you. However, the final success of your program will depend on your own ingenuity and salesmanship.

BUILDING QUALITY CONTROL

Kenneth Rosengren
Houdaille-Hershey Corporation

Like building great bridges, long roads, high buildings, Quality Control must be planned. Hit and miss methods like the log across the creek may suffice for a time, but soon their usefulness and permanent satisfactory results pale.

To present a satisfactory plan, the full scope of necessity must be considered.

Most manufacturing businesses can be covered in fairly identical ways by a breakdown to the various segments that make up the whole. To delineate more clearly, let us take up the problem, step by step, covering the problems of local nature with each interval.

Our first consideration should be with the incoming raw material. This material may be sheet, bar or coiled steel; it may be wood, aluminum or any other substance with which we may work. It is reasonable to assume that if our raw material is satisfactory, our start has improved immediately.

How shall we go about determining the quality characteristics of our raw purchases? Visually it may seem satisfactory, but this is only a small part of the answer. Some questions we should answer are, What type of machine will the material be worked on?, What type of tools are to be used on it?, Is it a part to be formed or pierced on a press? and What are the specifications set up for it? The answers to these questions start you on your way to building Quality Control.

In most plants it is possible to determine the chemical analysis of the steel. This has always proven to be a very satisfactory approach. While the chemists are performing their job, let us look at the physical properties. If the steel is to be turned or formed, is it of the proper hardness? Rockwell or Brinell testing usually answers this question. Sizes and dimensions necessary for economic operation should also be reviewed and checked.

Granting we have determined our proper level of quality, the materials should be marked properly and binned to avoid using wrong materials purchased for other jobs.

Before we leave our receiving inspection, we must make sure we have our permanent records showing necessary details to help later in determining who of the various suppliers are sending us the better levels of quality. It makes for easier determination of who should be considered for future purchases. This is a real aid to the purchaser in any plant.

A second step, perhaps not applicable to all plants, could be a separate branch of receiving inspection where semi-finished or finished parts are screened. Here again the functions are not dissimilar to our previous discussion, but possibly more detailed and more monotonous. We think of a sampling setup because our suppliers have agreed to meet certain standards previously outlined to them.

In this type of commercial inspection, it should only be necessary to

check a small number of parts to determine a quality level of acceptable or unacceptable grade.

Too often haphazard methods are used to pass or reject lots of material. Many times too few and at other times too many samples are selected. Too seldom is the selection of parts for sampling done in a manner to assure the best results. Perhaps a short discussion of this phase of the job may be helpful.

It is very necessary to understand the end use of a part to make a proper selection of a sampling plan. Answer the question, How critical is this part?, and you won't fail to give yourself the protection needed. Can we afford to buy the part in lots where there are 2% or 3% or more defective? Is it necessary to screen 100%? What is the correct approach? Again, let me stress the necessity of knowing the parts end use. With this knowledge used to its fullest, the proper selection of a sampling plan will be made.

When the plan is known and the risk of purchasing bad lots and rejecting good lots has been determined, select the sample in the proper number and completely random. To more fully understand random sampling, we mean selection of samples from all parts of the container or containers where it is possible that any part in the entire lot could have been chosen.

In this way, and only this way, can you know your quality level and be sure you are right when a lot is accepted or rejected.

Keep records! Nothing is more valuable in again determining your supplier's ability to furnish parts in satisfactory quantities of a usable nature. You will find by doing this, the developed information will be extremely helpful. It is a fact that some vendors can do some types of work better than others and your records can be a guide in the selection of a supplier for parts of various designs or types, as everyone does not do everything better than another.

To amplify somewhat our observation above on knowing the end use of the part to be inspected, it may be well to review the part and attach to your blueprint those dimensions necessary to check. By using this method you are furthering the economy of setting up a sampling inspection department and limiting your plan to its reasonable necessities to obtain those assurances which are so important. Finally, be sure your inspectors know the reasons for their actions and the importance of correctly recording results. This may take time, but in the long run it pays.

Let us approach what may well be the most difficult step in our quality building program. This is manufacturing. Take your time, sell your idea, do not push it on a foreman or his men and by all means get them to work with you. You will find the task difficult enough with the best of cooperation.

A suggestion based on experience is to go slow. Select a part or dimension that is important to the end product and start your data accumulating. The hardest problem in the plant is not necessarily the best problem to tackle first, as a new tool such as Quality Control must show early results or too often the entire plan may be discarded. By this approach, you develop confidence in yourself and your men and the early results, good or bad, earn lasting gratitude when a solution is forthcoming. Stick with your first job with the tenacity of a bulldog, be-

cause there you will gain or lose. When the advice "go slow" is given, take it in its fullest meaning. Start the job with your selected inspector and after preliminary training work with him until you are sure he understands the full meaning of his job and has developed confidence to continue on his own. In working with your employee, check his various steps closely to be sure he is in the groove. When he approaches a machine to start his sampling of its product, be sure he knows where the parts he is to check come from. Be sure he understands he is to get these parts from the machine as they fall out and not have the operator hand him the samples.

It may appear that too much emphasis is being placed on things seemingly unimportant, but experience has dictated these rules. We follow them to the nth degree.

It has been our experience that measuring gages give us best results, but gaging for attributes may suffice in many instances. This is a problem of selection and may change with experience. The complete elimination of some charts may be indicated in instances where recorded data show no further need for them.

When your first chart is placed into being you may forget control limits for the time being. Be sure though, before setting limits is attempted, you have developed sufficient data to start. It is suggested that twenty to twenty-five sets of data be accumulated first. Also select your sample size, but where practical, five (5) may prove advantageous. The reason for this is the ease of handling and the simplicity of the arithmetic calculations.

Now that data is available, set your limits and determine how close to in control your process is. Where your $\bar{\bar{x}}$ chart is out of control here and your R chart is out there, your problems start.

To indicate more fully the importance of attacking problems from all angles, an interesting development occurred in our plant. One part of an assembly for an automotive application was to be made with a .003 step from center to outer edge where the step had to be held to close tolerances. The original Blueprint showed a tolerance of plus and minus .0001. Our processing engineers did not believe this possible. After some selling with our product engineering, there was some relenting and tolerances were increased to plus and minus .0003. With this ammunition, we began making sense to the operating department and to the processing group with the result that more cooperation of an immediate nature was obtained. Dies were prepared and a press was readied for the start and production became a fact. Our first charts indicated an out of control condition and that more work on the dies was necessary. With this done, we started anew. Our results, though better, were still of an unsatisfactory nature and more problems needed solving. Our next step was to work on the press. This included table alignment, spindle tightening, pressure regulation and other changes which gave us still better results and our charts began to show control. It was necessary to employ the time of four people to sort our production at the start, but after working on our problems continuously, this number gradually reduced to one as control of the operation was indicated. We again reviewed the dies and found a small change in step heights on the die gave us still better results, making it possible to eliminate 100% sorting in its entirety. As we knew any reduction in variability of this step meant better end

production, as concerned our final assembly, further efforts were expended until today, perhaps six to eight months after our beginning we have reduced our problems to a minimum and have reduced our tolerances to the original plus and minus .0001. It paid off.

We have had other problems of a similar nature on which our approach has been the same. Some we cured in a short time, but others are still with us. This, however, is building Quality Control. Each success, regardless of the failures encountered, has developed a confidence that our foremen would not work without charts. They have seen the wisdom of using a quality tool of this nature and want its comforting protection.

Our next step in the program building Quality Control was the sub-assembly and final assembly and its functional check. Our problem was only one of manpower to check our production 100% and eliminate unsatisfactory assemblies. This is easy whether it is your product or ours. Is it the right answer? Definitely, no! Why, if you have a controlled production is it necessary to 100% your end product? It isn't! Where originally six operators ran testing machines, now only two do the same job and on a double sampling basis.

In installing a sampling plan of this nature, you must build confidence in your operator. Regardless of the means used, if intelligently approached, you can win your candidate over to your side. An explanation of the "how" may make this point more clear. As our product arrived at the test machines in small lots, it was easier to put across our point, but the same application can be made where lots are larger. Our approach was specifically this. We explained fully to the foreman and one operator the plan, then started him on his way. We did, however, lay a great deal of stress on random sampling. When this point was clear, our sampling check was made on the first lot. Fortune was with us in this particular instance and the lot passed on the first sample. Our operator, however, was not sold. To further convince him of the sanity of this new approach, we had him check all the remaining instruments in the lot. Again luck smiled, and no rejects were found. This was repeated several times until the operator got used to the idea that the plan not only was workable but we still eliminated most of the rejects by using it. However, it should be pointed out that a full month and constant showing was necessary to build this step of our Quality Control before full acceptance was evident. The end result is rather amusing. When a bad day arrives and more second samples are necessary, bad tempers are in the majority.

This takes us to our next step in our program. When we have an unusual number of rejects for any one reason, we disassemble and backtrack on our product for an answer. Very often it is bad or careless assembly, such as using wrong parts or even to parts being missed, but when the answer is determined, the cooperation from our productive group is tops. They cover all the bases quickly to stop the trouble. Time is taken to fully explain and re-explain why things must be just so and what results when this is not so. This is the result of a constant quality approach, building and instilling it by day, by week, by months.

Our last step and certainly a most important one is the control of gages, fixtures, etc. Gages particularly require checking at varying intervals. Some daily or by shift and some at considerably longer intervals. Our experience has dictated that a constant follow-up is necessary and pays

off. Here again records are helpful, however, we discarded written records for a more economical method. When gages are brought to our air-conditioned gage room, they are permitted to cool to room temperature, usually 70 °F., and then the checking is done. We use the standard methods of checking, such as using masters of block or cylindrical type, and plug and thread masters as needed. In some instances super micrometers are employed and again we may vary our techniques. This is augmented by the use of color identifications painted on the gage handles to indicate the month and week in which the gage was last checked plus the use of added color for the day when necessary.

Confidence, built soundly by the continued knowledge that parts and materials are of the proper quality level plus understanding cooperation between operating and service departments, plus the attainment of a real goal by Quality Control methods will build for any industry Quality Control with results. Imagination, application, cooperation and perspiration are the four ingredients necessary to assure your building success.

QUALITY CONTROL AS A METHODS IMPROVEMENT FUNCTION IN AUTOMOTIVE & AIRCRAFT PARTS MANUFACTURING

E. F. Gibian
Thompson Products, Inc.

The Fifth National Convention of the American Society for Quality Control marks a milestone in the growth of our relatively young Society. Statistical Quality Control has now spread widely through the industry of the United States, and as it is losing the glamour of a new science or technique, it is gaining in the intensity of its development and application. Statistical Quality Control has come of age. It therefore appears appropriate to pause and take stock! Where do we stand and where do we go from here?

The Automotive Technical Committee has set up this program to discuss quality control aspects of particular interest to the manufacturers of parts and subassemblies. The J-35 Allison jet engine displayed in our exhibit at this Convention is one sample of the aeronautical products for which we manufacture parts, components, subassemblies, and accessories involving difficult materials and high precision. Statistical quality control procedures in receiving, manufacturing, and inspection of automotive and aircraft products have been used for about eight years, and the experience thus gained, together with a few simple examples from our practices, will serve as a framework for suggesting the answer to the question, "Where do we stand and where do we go from here?"

In appraising the present status of statistical quality control in industry, particularly in the automotive and aircraft field, a fundamental weakness appears to be its limited scope of application. In turn, this limited scope may be the result of the organizational set-up under which this function is being administered in most plants. Not counting a few notable exceptions, statistical quality control has grown up as an adjunct to the inspection function and has remained there, its use being limited mainly to watching over the quality and signaling either compliance or non-compliance with specifications by means of control charts and sampling tables.

Thus, statistical quality control has been utilized as a weapon of defense against waste, mistakes, and carelessness, its avowed purpose being advertised as a means of quality improvement, or, to quote verbatim from the prospectus of this Convention, "Quality Control by statistical methods is an established tool for improving and maintaining quality standards". That describes exactly the point where we stand today. Now an army equipped with modern tanks may occasionally use these tools of warfare to good advantage for defense purposes, but their principal value lies in their mobility and offensive ability to lead an attack. Similarly, statistical quality control is destined to be a tool of industry used for attack, an analytical means for attacking all sorts of industrial problems and bringing about improvements in the entire production process. Up to now, statistical quality control was almost exclusively a vehicle for deductive thinking. The time has come to turn to inductive, creative thinking, to broaden the base of statistical quality control, to apply it to process and management controls; in other words, to let it serve the broader function of methods improvement.

This concept of the function of statistical quality control may be a controversial point, but companies which organized quality control programs on this basis produced remarkable results. The use of statistical methods in quality control is only one of the many fields of application. Equal emphasis should be given to statistical analysis in search of improved production processes, time study and standards engineering procedures, tooling improvements, inventory control, cost control, personnel management, and all other activities where chance variations influence the results. Statistical quality control engineers should be ready and able to serve the entire organization and all departments.

As long as statistical quality control is considered a tool for improving and maintaining quality standards, it is quite natural to assign the administration of these statistical methods to the quality manager or chief inspector. This is the conventional type of organization prevailing in most plants. To avoid any misunderstanding, this is no adverse criticism of such an organizational set-up. In fact, the excellent results in quality improvements and in economies of inspection at numerous plants amply demonstrate the valuable achievements obtained where competent inspection personnel undertook the application of statistical quality control procedures. But if we accept the contention that statistical control methods are profitably applied to the broader field of methods improvement, not limited to the area within the jurisdiction of the quality manager and chief inspector, then we have to create a different organization for the administration of the statistical quality control program.

In the larger Thompson plants -- by way of example -- the administration of statistical control procedures is assigned to the Statistical Control Department reporting to the division industrial engineer. This department is essentially a service department with the responsibility to conduct research and develop improved methods wherever statistical techniques may be applied. These statistical control engineers are members of the industrial engineering team, in which are integrated the functions of standards engineering, job evaluation, budgetary and manpower controls, methods engineering, and plant layout. In turn, all Division Industrial Engineering Departments are governed by the policies and procedures established in the Staff Industrial Engineering Department under the direction of the Chief Industrial Engineer, whose staff of specialists includes also a staff statistician. This staff statistician not only acts as consultant to the divisions' statistical control engineers; but he also directs the training of statistical personnel, designs and, if necessary, conducts initial training classes for operating supervisors, including plant managers, inspectors, and technical personnel; and of course acts as a focal point for the exchange of information and the dissemination of significant developments in techniques and new applications.

Under such a set-up, the introduction of statistical quality control to inspection procedures is handled by the Statistical Control Department, just as any other type of methods improvement. Of course, the quality manager or the chief inspector and his corps of inspection personnel have acquired the knowledge of statistical control principles, but they rely upon the craftsmanship of statistical control engineers to develop control charts, sampling schemes, and quality audit techniques, just as the plant manager and his foremen rely on specialists;

methods engineers, to furnish them with improved manufacturing and material handling processes. The statistical quality control program, while designed and constantly improved by the statistical control specialists, is operated by the inspection personnel, and this mutual interplay of interests is no doubt the main factor for the dynamic growth of the statistical control program in our organization.

Control engineers, not burdened by the day-by-day pressure of the inspection operating task, are in the advantageous position to apply their knowledge to a broader field which is of utmost importance to a progressive plant management, particularly in the precision manufacture of parts and subassemblies. This expansion of statistical control techniques beyond the limited scope of quality control proper leads into methods improvements of processes and procedures which would otherwise be difficult to achieve without such a group of specialists expressly organized and trained for that purpose. This is where initiative and inductive thinking come into play.

Yet, there is one more condition which has to be met to create a favorable climate for this concept of statistical quality control applications and to insure its vitality and growth. An understanding of fundamentals, principles, and basic techniques of statistical quality control must be imparted to factory supervision from the management down to foremen and supervisors, to department heads, engineers, technicians, accountants, purchasing agents, and personnel supervisors.

This training, by means of carefully planned elementary courses, which incidentally can be made quite lively and entertaining, is far from formidable. A description of such a training program would exceed the scope of this discussion, but let it be said at least that this honest-to-goodness training in fundamentals is less costly and more effective than the sometimes encountered abortive schemes of promoting statistical quality control by ballyhoo, posters, cartoons, and advertising ā la singing commercials. The informed supervisor, while not a statistical technician, will sense where statistical procedures may help to solve his problems and will promptly present them to the control engineers. This is exactly what is happening in our plants, and such terms as frequency distribution, range, three sigma limits, etc., are part of many a supervisor's vocabulary. There is no doubt that this wide-spread use and knowledge of statistical quality control applications contributes to the quality and methods improvement mindedness of an entire organization.

Statistical quality control as a methods improvement function is practiced in a number of companies. It is a natural development of the art, neither originated in nor limited to the Thompson Products' plants. But, for purposes of illustration, a few examples from our practices are presented. They have been selected because of their simplicity so they may be readily understandable to those whose experience in statistical quality control is of an elemental nature.

Written requests to the Statistical Control Department to investigate "complaints" and their disposition are recorded on the form illustrated in Figure 1. A supervisor from any department of the plant may originate such a request. The written request is first analyzed to determine whether it justifies investigation by a quality control eng-

THIS COPY TO DEPT.

TO: STATISTICAL CONTROL DEPARTMENT

COMPLAINT RECORD

NO. 53

ORIGINATED BY:	GENERAL FOREMAN'S APPROVAL	DEPT. NO.	DATE
Lesak	C. F. Anspach	633	1-27-51

PART NAME	CUSTOMER'S PART NO.	F.R.
Stator Blade	6301 - 9482784 6301-1 8496848 6301-2 9451762	6301-4

COMPLAINT

Leading Edge of O.D. on blade has a dip in it which causes trouble in sizing the blade.

This condition is caused by forge shop.

18435 also has same dip in it.
6071 also has same dip in it only on "I.D" of blade
6077 has same dip

INVESTIGATED LOCALLY — DATE	ASSIGNED TO ENGINEERING — DATE	ASSIGNED TO LABORATORY — DATE
1-26-51	1-30-51	

ADJUSTMENT

Study of control charts, die records, and inspection data show that width of sizing die pads is the direct cause of this trouble. Engineering is opening up pads as shown on attached sketch. First experimental die tried out on FR6301-4 produced good pieces.

INVESTIGATOR	ISSUE DATE	DEPARTMENT HEAD
to follow up K. V. Ward	2-6-51	W. H. Coughlin

Figure 1. An example of the form used for processing requests for investigations.

ineer, or whether it should be handled by some other party. If the complaint warrants investigation, a number is given to the request, and the handling of the case is assigned to a quality control engineer. He may be able to work out the solution by himself, or he may engage the services of the Engineering Department or the Laboratory. After the case is finished, a completed "complaint record" showing the complaint and the action taken is issued and forwarded to the originator, interested members of the supervision, the quality manager, the product engineer, the division industrial engineer, and the division manager. All information and data pertinent to the investigation are permanently filed in the Statistical Control Department. Many methods improvements result from such a procedure, the case covered by the illustration being a typical example.

The second example, Figure 2, is the result of a study undertaken upon the request of a time study supervisor, to determine the number of valves that can be finish ground on the stem within the specified finish tolerances on one dressing of the grinding wheel. The chart represents a condensation of the findings collected from measurements made under controlled conditions at various grinding wheel diameters from the time the wheel was new until it was dressed down to the smallest useful size. The micro-finish readings of the valve stems were plotted, the curve shown on the chart being the statistically derived correlation between surface finish and number of pieces per dress, with practically all of the readings within $\pm$ 3 standard deviations. The upper 4 sigma limit was adopted as a safe basis for computing the wheel dressing allowance as well as a guide for the operator. For instance, to insure a finish of maximum 18 micro inches, the grinding wheel is to be dressed every 142 pieces.

Control of visual inspection applied to precision aircraft parts is a difficult task because measureable quality standards cannot be set for many critical characteristics, acceptance or rejection being largely governed by the subjective judgment of the individual inspector. The chart, Figure 3, gives the history of a case where variations in visual standards between shifts were analyzed by a statistical control engineer and eventually eliminated. The example deals with the visual inspection, under a twenty magnification binocular, of a turbine bucket for such defects as surface finish blemishes, nicks, scratches, pits, and imperfect blends. Samples of pieces not passing inspection were taken from each shift and were reinspected by the inspection foreman to determine how stringently each shift was adhering to the visual standards specification. It was soon evident that the second shift was too critical and rejected or sent back acceptable pieces for repair and rework. With these data on hand, it was possible to institute the necessary corrective steps. Visual inspection standards were more clearly defined and the second shift inspection supervisor and his inspectors were given proper instructions. The chart shows clearly how the cooperation between the Inspection Department and the Control Department eventually brought about a uniform inspection level between all three shifts.

How statistical control engineers may participate in cost control decisions is illustrated by the simple example of Figure 4. Jet engine compressor blades were wet tumbled to clean out the fillet in the areas forming the transition from the airfoil to the root, this cleaning operation being necessary in order to obtain reliable indications

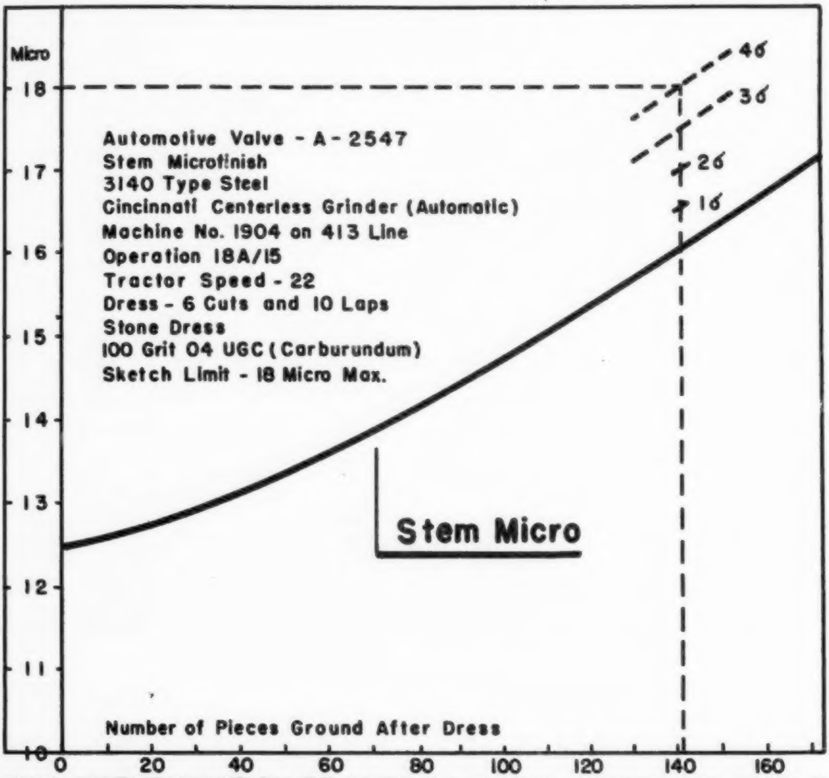


FIG.2. DETERMINATION OF OPTIMUM WHEEL DRESSING CYCLE

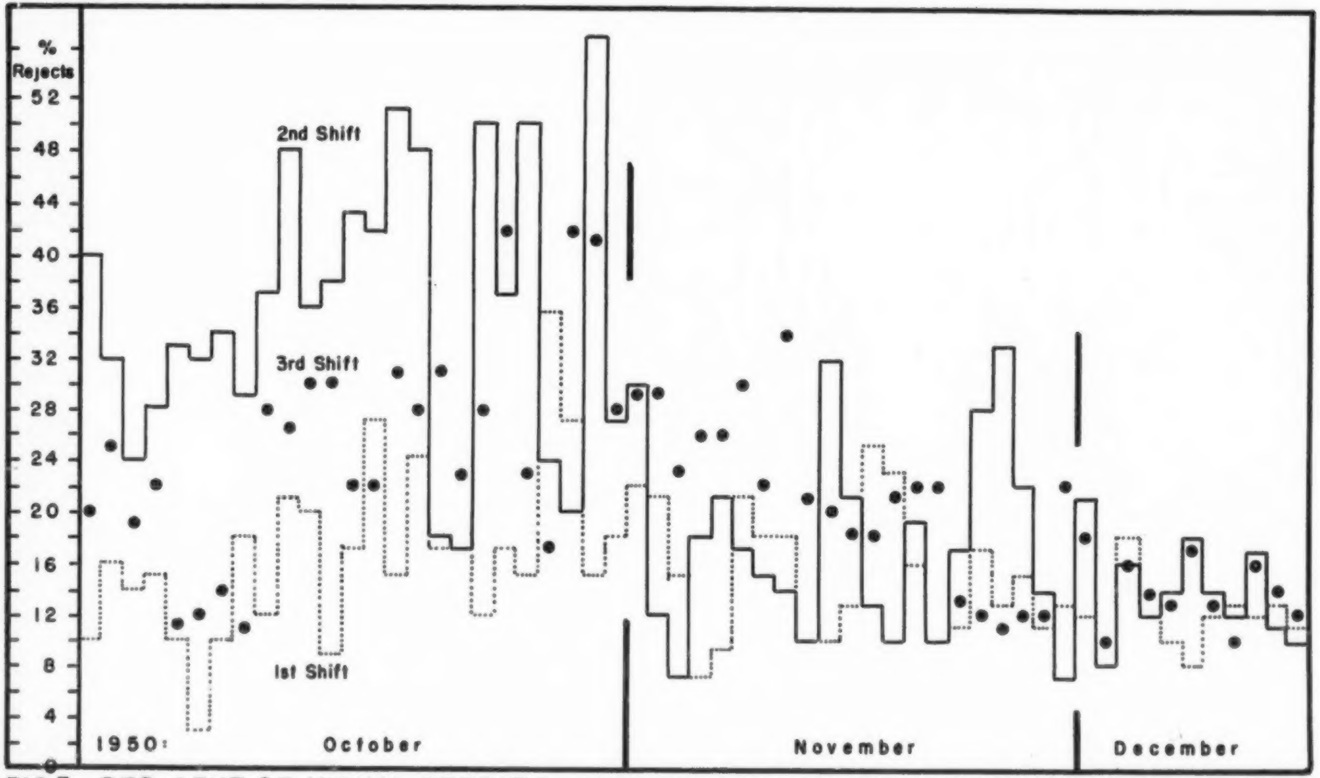


FIG.3. PER CENT OF VISUAL DEFECTS BY SHIFT FROM OCTOBER 1ST TO DECEMBER 14, 1950
20 x Binocular Inspection HJ - 4102 Bucket

in the subsequent magnaflux inspection. This tumbling operation always produces a certain percentage of nicked or scratched blades which have to be repaired. The repairs add to the manufacturing cost of this tumbling process, increasing with the percentage of nicked blades, as shown on the chart. An alternate process of cleaning the fillet surfaces by a polishing operation may be employed, its cost per 100 pieces remaining constant because no repairs occur. Quality records were maintained for each type of blade, tabulating the average percentage of blades rejected for nicks and scratches in tumbling. The chart was prepared by the Statistical Control Department to show that it is more economical to replace tumbling by polishing when the percentage of blades rejected in tumbling exceeded 26%. At the same time, the control engineer instituted a thorough study of the tumbling process, employing control charts to determine the effect of tumbling speeds, loads, cleaning agents, and other variables upon the amount of nicks and scratches. Improvements in the tumbling operation were thus accomplished, lowering the amount of nicks and scratches, but the chart still holds good as a criterion when to tumble and when to polish.

The Personnel Department turned to our statistical control engineer for a departmental analysis of the labor turnover. A modified "p" chart, reproduced in an abbreviated form in Figure 5, put the spotlight on a few departments where the percentage of "quits" exceeded the control limit based on the plant average. Surprisingly enough, an investigation of these departments by the personnel manager brought out a suspected assignable cause -- the faulty administration of personnel practices by the department foreman or supervisor. It was easily corrected by the proper instruction of these men.

These examples were chosen at random to illustrate the potential broader function of statistical quality control, reaching beyond the conventional quality applications. More complicated cases would show how statistical investigations led to partial or complete redesigns of fixtures and entire machine tools; how foundations and mountings of precision tools were altered to keep the process under control; how layouts of production lines were planned to accommodate AOQL continuous production sampling inspection; how a statistical study led to the development of a precision forging process for automotive valves effecting economies in subsequent machining operations; how ratio delay determination through random observations and control chart techniques rendered time study standards more reliably and economically than conventional methods.

The Statistical Control Engineer in the precision manufacturing industry can render a greater service by applying Statistical Quality Control techniques to methods improvements!

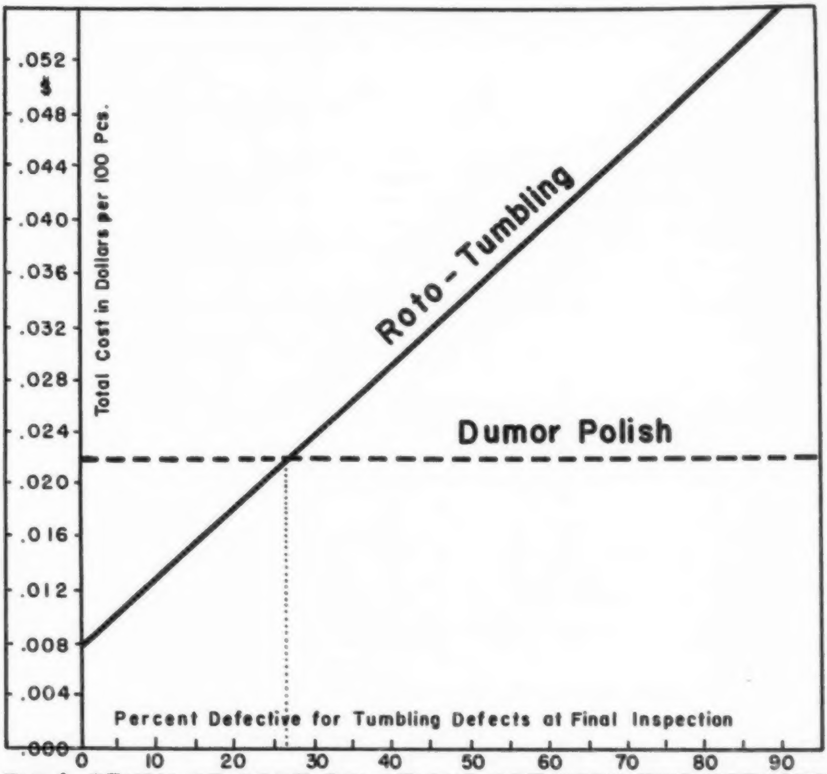


FIG.4. STUDY OF COST RELATIONS BETWEEN TWO METHODS

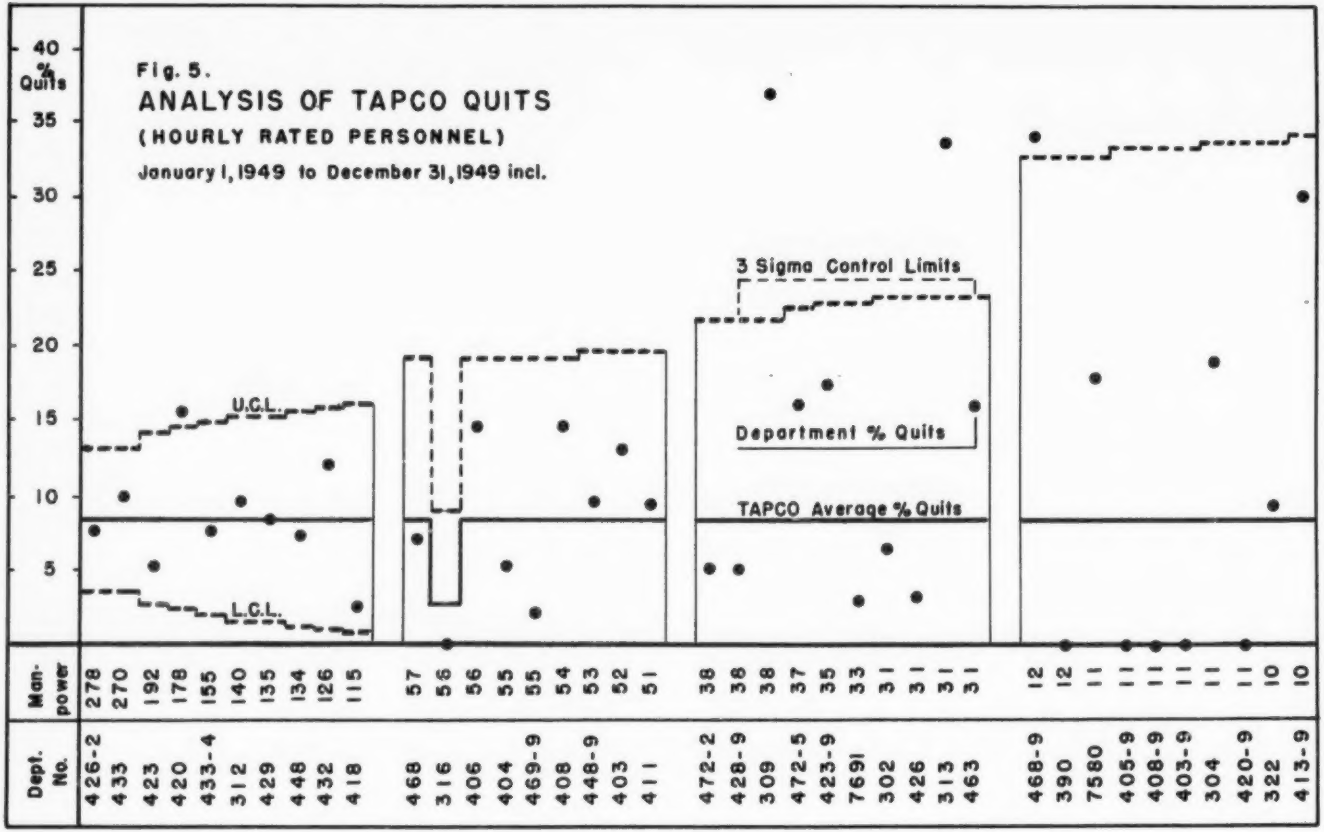


Fig. 5.
ANALYSIS OF TAPCO QUITS
(HOURLY RATED PERSONNEL)
January 1, 1949 to December 31, 1949 incl.

AN APPLICATION OF STATISTICAL QUALITY CONTROL TO MALLEABLE FOUNDRY OPERATIONS

Edwin F. Price
Dayton Malleable Iron Co.

In the foundry as in other industry, quality cannot be profitably inspected into the product. In order to produce castings of high quality profitably, the quality must be made into the casting at each stage of th manufacturing process. This must be done by controlling each operation beginning with melting and carrying through the sand mixing, core making, molding, annealing, grinding, straightening, and finally the painting. I each operation is under control a quality casting will result. If some means is employed to keep these operations in control, then the foundry can be assured of a high quality product. One way to maintain control of an operation is by the use of statistical quality control.

The application of statistical quality control to foundry operations i a detailed process because of the many variables which affect the dimensions, finish, soundness, and physical and chemical properties of a casting. In order to realize the maximum benefits of statistical methods all variables must be controlled.

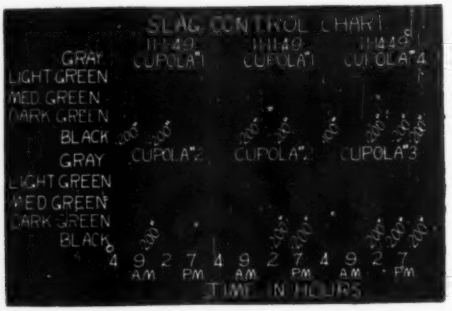
In order to follow the procedure by which we apply quality control in our foundry, we will actually go into the foundry by means of a motion picture, and follow one casting through the plant, starting from the scra pile and following through each stage of its development, and finally see it loaded on a truck at the shipping dock. We will show as many slides as time will permit of the various controlled dimensions of the casting.

The foundry operation actually starts with the melting of the iron. The scrap is sampled while still in the car, and a chemical analysis is performed to check for undesirable elements. The other raw materials suc as coke, pig iron, silvery iron, spiegle, etc. are also checked, even though they are purchased to definite specifications. As the melting tak place a close chemical analysis is performed on the metal. At the same time slag samples are taken for control purposes.

Slide #1 shows the type of control we use for our slag. While this is not a quality control chart as you know it, it is a type of control chart which has been very helpful in the control of the melting operatior The desired slag color is green. Any darkening of this slag color is indicative of oxide pick-up of the slag due to a burning out or lowering of the coke bed, or of too much blast, or both. Actually it is not the colc of the slag so much as any change therein that necessitates action on the part of the operator. The dark line on the chart shows the ideal slag, and the dotted line shows the point of danger in the melting operation. On 11-1-49 it can be seen that there was a definite period of oxidation due to a low coke bed at 10:30 A.M. on both of the cupolas. This fact would be borne out if you could see the chemical analysis for the iron at that time, showing a drop in carbon and silicon. The points with the figure "200" mean that 200 pounds of extra coke were charged. The other charts from 11-11-49 and 11-14-49 show good operation.

The chemical analysis of the elements checked is also plotted on a control chart. The chart showing the carbon, silicon, and temperature

is shown on slide #2.



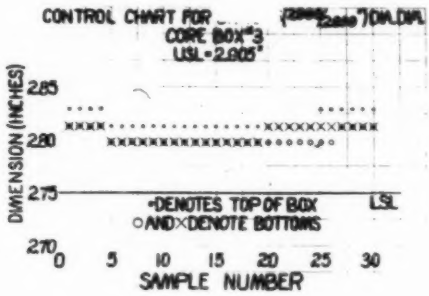
Slide #1

Slide #2

The charts shown are not the $\overline{X}$ and R charts, but the charts actually used at the furnaces to record the analysis as it comes from the laboratory. Each group of ten is averaged and plotted on an $\overline{X}$ and R chart and the control limits calculated and plotted on these daily charts. These charts were valuable in that they provided a picture showing the operators exactly what they were doing, and a keen rivalry developed to see who could maintain the best control. This further resulted in closer control and a lower range. The chart for December 8, 1949 compared with the four charts from July, 1949 shows the results of applying quality control to the melting operation. As a further aid to melting operations control charts are also maintained on the humidity and weather conditions.

We are now ready to start making the cores for the casting we are following. Since the cores of a casting often make critical dimensions in the casting, it is important that the cores be properly made, and that all critical dimensions made by the core be measured in the box and plotted on a control chart. The box will wear very gradually, therefore it is necessary to measure the critical dimensions of a core box only once a day. We have found that the best way to keep control of a core box dimension is to plot each day's measurement on a regular graph chart on which the

upper and lower specification lines are drawn. A typical chart is shown in slide #3.



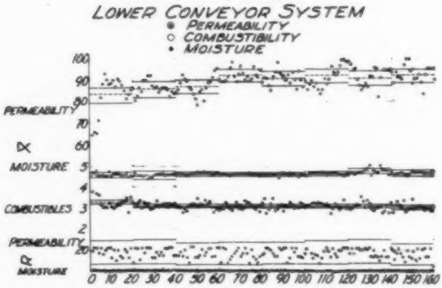
Slide #3

You will note from slide #3 that there are three parts to each box, and that the critical dimension, in this case the 2.998/2.999" Fin. Dimension, is measured on each part of the box and plotted separately on the chart. You will note that one of the bottom parts started to show wear at about reading #20. The top reflected wear at about reading #25, and the other bottom did not reflect wear until reading #27. While the box is showing wear, there is no need for action to be taken until the upper specification line is approached. In the process of enlarging the chart for slide purposes the upper specification line was not included. It can also be noted that the box is made at or near the lower specification to allow for maximum wear before repair or renewal with a new box.

In addition to this type of control we also measure other types of core controlled dimensions such as out-of-round diameters, and plot these on $\bar{X}$ and R charts to assist the core room foreman in maintaining better control of his cores. Core hardness charts are also helpful to the foreman in checking his core mix and baking time.

The next operation is that of molding sand preparation. The molding sand is made up of used foundry sand, core sand which adds itself at the shakeout, and sharp sand additions. The sand goes from the storage bins to the muller, where it is conditioned for molding. The additions of water, clay, sea coal, etc. are made at the muller and must be properly controlled to produce a mold of proper permeability, strength, hot strength, etc. and still give a good finish.

Slide #4 shows the method by which we control our permeability, moisture, and sea coal. The permeability shown in the top section of the chart is very low initially, due to a high percentage of fines in the system. Once this condition was corrected, most of the points fell between 80 and 100, which is the desired permeability for the type of casting we make on this line. The high range and the variation in $\bar{X}$ are due to the sand system being overloaded, and thus not allowing sufficient time to condition the sand to the point of close control of permeability. This is also reflected in the variation in combustibles. The range chart for the combustibles was omitted in the process of enlarging the chart for slide purposes. The moisture shows good control and a very good R chart.

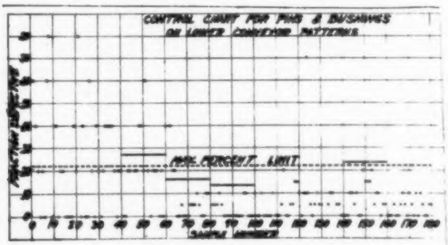


Slide #4

In addition, a screen analysis is run on the sand in order to maintain the proper grain distribution. The results are plotted and the sand is held to a definite normal distribution. Any deviation from the desired curve is adjusted by sharp sand addition or by removing the fines by a blower.

The next operation which we will follow will be the molding. Along with the melting the molding ranks as the most important foundry operation and must be carefully controlled. The patterns must be accurately made, and dimensional surveys are run on production castings to determine what changes must be made in the patterns to produce the castings to blueprint dimensions. The pattern must also be properly gated in order to produce a sound casting with a maximum yield. The gates must also be placed so that they can be removed economically and not interfere with machining operations.

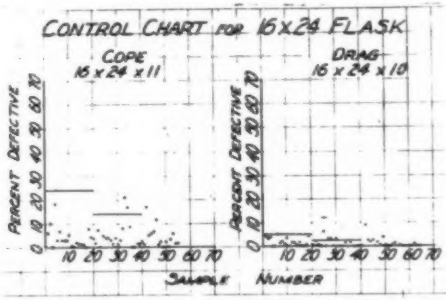
While the patterns are in the sand they are checked at definite intervals for loose core prints, risers, inserts, dowel pins, and other pattern defects. The pins and bushings are also checked by gauging, and the results are plotted on a p chart.



Slide #5

Slide #5 is a p chart for the conveyor line on which this casting is made. This chart reflects the complete lack of control resulting from poor and improper inspection of this phase of our equipment. Once the gauges had been standardized and a systematic check made of all our pattern equipment we attained a good control, which can be seen starting with sample #65. This chart is calculated on a basis of five cope and drag stations on the line and two pins and two bushings per station, or a total of twenty pins and bushings.

The flasks are also checked for defective pins and bushings, and the results plotted on a p chart. Slide #6 shows such a chart for the flasks used in making the casting which we are following.



Slide #6

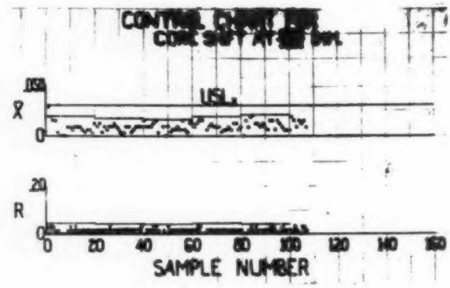
The flasks are checked once a week, and the defective pins and bushings replaced.

Since these charts were put into use, there has been no record of a casting made in a tight flask being scrapped for cope and drag shift due to defective pins and bushings.

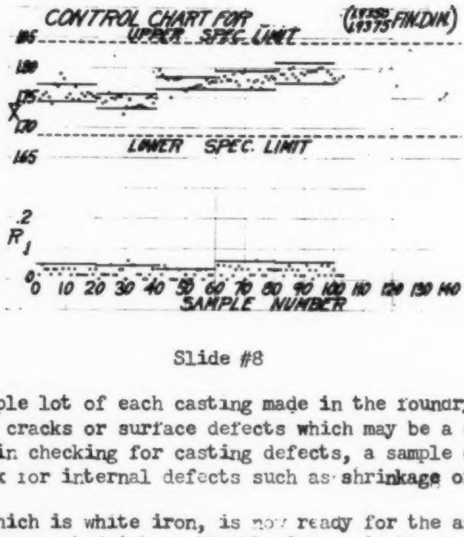
When the casting comes of of the shakeout it is a white iron casting and very brittle. The casting is cleaned and sent to the hard iron department where it is given a visual inspection, and the fins removed. All critical dimensions are checked and plotted on $\bar{X}$ and R charts. Slide #7 is an $\bar{X}$ and R chart for core shift. It can be noted that not one sample exceeded the upper specification limit, and aside from the first sample, not one point is out of control. It can be seen that all upper and lower control limits are calculated every twenty readings.

Slide #8 is of interest because it shows how an $\bar{X}$ and R chart reflects core box wear. Starting with the 40th reading, a gradual increase in the dimension can be noted. This increase is due to core box wear. When the upper control line reaches the upper specification line the box must be repaired. Since it is not economical to repair equipment before it is needed, these quality control charts have been most useful not only in maintaining the quality of the casting, but also in assisting us by showing when repair is needed.

$\bar{X}$ charts are also used to assist in the control of casting weights.



Slide #7



Slide #8

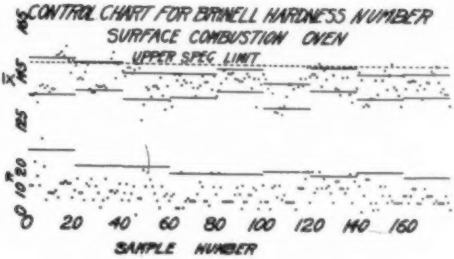
Each day a sample lot of each casting made in the foundry is checked on the magnaflux for cracks or surface defects which may be a cause of scrap. As a further aid in checking for casting defects, a sample of every casting is broken to check for internal defects such as shrinkage or blow holes.

The casting, which is white iron, is now ready for the annealing department, where it is converted into malleable iron. As the castings come from the annealing ovens, a sample lot is checked for hardness on the Brinell machine, and the B.H.N. plotted on an $\bar{X}$ and R chart.

The maximum specification of 149 B.H.N. is shown by the dotted line in slide #9. The upper and lower control limits are shown in heavy lines. When a sample shows the hardness out of control and above the specification limit, the iron must be reannealed.

Sample bars are poured from each day's heat and put through the anneal ahead of the heat to determine in advance what controls may be necessary in annealing the iron. The B.H.N. is plotted on control charts, and the bars are broken to observe the fracture. Samples are cut and polished for microscopic examination to check the structure and measure the decar-

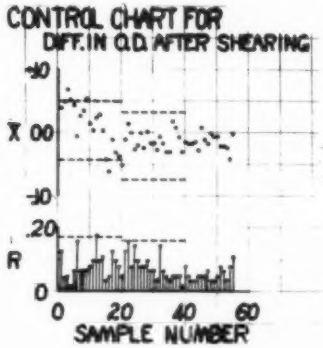
burization and frame, if any.



Slide #9

Tensile bars from each heat are annealed with the castings and sent to the laboratory to be pulled. The ultimate strength, yield points, and percent elongation are plotted on control charts.

The casting is now sent to the soft iron department where the gates are removed, the fins chipped or ground, and the casting cleaned. As the gates are being sheared or ground, a sample is taken to check the operation. Slide #10 shows an $\bar{X}$ and R chart for such an operation.



Slide #10

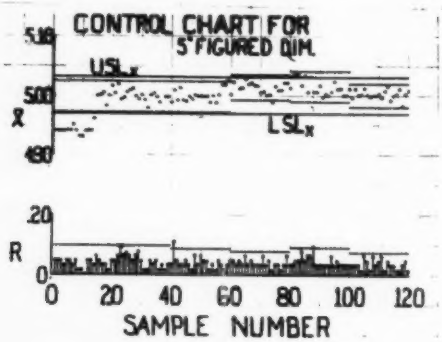
The gate is on the flange at a chucking point. The flange is checked across the sheared area and the data plotted as plus or minus the correct dimension. The first group of twenty readings shows poor control, but this condition was improved after the die was changed to properly locate the casting under the knife. Similar use is made of control charts on grinding operations.

When the gates are not located on critical dimensions, a chart is used as an aid in controlling over and under clipping or grinding.

The casting is now cleaned and sent to the finishing department where

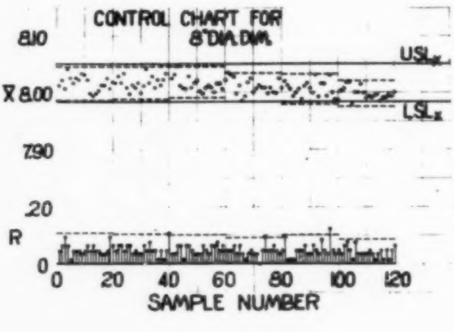
it is straightened and given its final inspection operations.

While the castings are being straightened a sample is taken to be checked for all die control dimensions. Slides #11, 12, and 13 show some of these dimensions on the casting we are following.



Slide #11

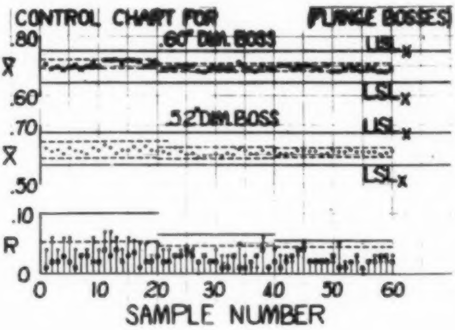
Slide #11 shows the control chart for the five inch figured dimension between the pedestal legs of the casting. It can be seen that the first fourteen groups are below the lower specification line. Since this dimension is controlled by the head of the die, a new head was installed at the fifteenth group and this corrected the discrepancy. The upper control limits exceeded the upper specification limit between groups 80-100. This was not the fault of the die, however, but was due to the castings being crushed in the annealing ovens to such an extent that the die could not possibly bring them back. When this was corrected in the annealing department, the control charts reflected good operation.



Slide #12

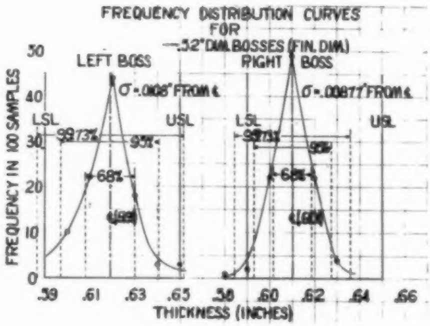
Slide #12 shows the control chart for the eight inch dia.dim., which is an unfinished dimension. However, the customer takes a clearance cut at this point to insure ease of assembly of the part. The lowering of the control limits starting with the 60th group is not due to die wear, but is due to a pattern alteration. This alteration was made at the request of

the customer to reduce the number of pieces which needed a clearance cut, thereby increasing the tool life.



Slide #13

Slide #13 is the control chart for the locating bosses for the first machining operation. Since the customer locates on these bosses in his first operation, and since any error in the bosses will be reflected into the other machined dimensions, these bosses must be properly controlled. The .60 dim. boss is plotted with an "x" and the .52 dim. boss with a dot. The upper and lower specifications are drawn in heavy lines, and the upper and lower control limits for $\bar{X}$ are plotted in dash lines. The ranges are plotted in a similar manner, except that the heavy lines denote the control limits for the .52" dim. boss range and the dash lines denote the control limits for the .60" dim.boss range.



Slide #14

One of the best sources of information which can be obtained about a critical dimension or an operation is a frequency distribution curve. When we are checking an operation, investigating a control chart which shows lack of control, or checking samples from a new pattern, we run a survey and plot the data to check for normal distribution and to determine whether or not the specifications can be met. Slide #14 shows the survey which was run on both of the .52" dim.bosses, one of which is shown in slide #13. The correct rough casting dimension should be .62"

because of the .100" finish stock on the face of the flange. The left boss shown in the left curve is very good. The curve is good and the mean is .6191, which is very close to .62. The right curve is good, but the mean is about .010" to the left of .62. Therefore .010" was added to the right boss to make it conform as nearly as possible to the correct dimension of .62.

The casting is tested for leaks under ten pounds of pressure while submerged under water. The leakers are easily detected by the air bubbles, and a p chart is helpful in keeping the leakers under control.

When the final visual inspection is completed the castings are ready for painting. The paint is checked for viscosity and percent solids as a receiving inspection precaution to insure that it meets specifications. During the painting operation the tank is checked periodically with a #4 Ford viscosity cup, and the results plotted on a control chart.

In conclusion we feel that quality control is a valuable tool in the production of quality castings. When control charts are used on critical dimensions and operations, we know before the castings are shipped that they can be readily machined in the customer's plant with a minimum of scrap. The charts are a reliable tool in tracking down trouble in our operations and equipment, and show our supervision when action must be taken to prevent large scrap losses. This fact has proven itself in the past two years by a decline in our scrap accompanied by a reduction in costly rework and rehandling.

We have been able to reduce the number of gauging operations formerly required in our inspection, and at the same time reduce the amount of scrap in the customer's plant to the lowest point in the history of our plant.

SOME QUALITY CONTROL APPLICATIONS IN THE ALUMINUM INDUSTRY

W. P. Goepfert
Aluminum Company of America

Any Quality Control Program should have as its goal the production of a product or the performance of a service to the satisfaction of the consumer at a minimum cost. The term "consumer" in this statement is to be considered in the very broad sense of including any other department of the same producing or servicing company or a subsequent operation within the same department as well as the customer for a finished product. Under the conditions of world strife that are again being experienced, there is too often a tendency for the free use of the statement that "cost is not a factor". The same circumstances that lead to the use of this expression, however, are the causes prompting the imposition of Government allocations and controls of various sorts with the objective of conserving materials, machines and manpower and directing their utilization for assigned purposes. It must be realized that costs are materials, machines and manpower with particular emphasis on manpower. Costs, therefore, should become an even more important consideration in times of high production for defense purposes than under normal peace time operations.

In normal times, industry is extremely conscious of costs and customer satisfaction in the interest of survival under competitive conditions. The post World War II era, although short lived, was feeling the influence of the "buyer's market" with its demands for desired quality at competitive prices. The "buyer's market" is again fading into the background as preparedness programs develop and industry is geared to military production. In the interest of national welfare, all possible effort must continue to be made to produce products to quality standards suitable for the intended purpose at a minimum cost. Only by such effort can available raw materials, machines and manpower be economically utilized. Quality Control Departments are in a position to offer major assistance to this end.

To economically supply the quality required for a particular application, it is basically sound that an accurate knowledge of that required quality be known by the producer. As in most industries, the aluminum industry has for its products certain characteristics which are considered standard. For characteristics such as mechanical properties and dimensional tolerances, these standard qualities are formalized in published tables appearing in sales literature and commercial specifications. Other characteristics such as surface finish, degree of porosity in cast products, degree of freedom from stains, etc. do not lend themselves so readily to positive description but, nevertheless, have a certain accepted level of quality in standard products. The maintenance of these standard quality levels requires expenditure of effort in processing, inspection and reworking. Additional operations are often necessary to provide this standard quality. For example, the production of standard straightness in an extruded product requires a straightening operation. If the degree of straightness described by standard tolerances is not important in the end use of the extrusion, it might be possible to satisfy the straightness requirement of the customer without expending so much time and effort in the straightening operation. At the same time, if ductility is an important factor in subsequent operations by the customer, it will be to his benefit if the extrusion is not given further cold work such as would be induced if further straightening operations were performed. Unless the

facts are known to the producer, considerable time and effort might be wasted in building into a product a quality characteristic that is not significant to the consumer and at the same time lowering the level of a characteristic that is of importance.

Visualizing the possibility of being of greater true service to its customers, if more detailed information were available on the end use to which its products were to be put, Aluminum Company of America created a system known as Quality Requirement and Special Practice Records. This system was put into operation in 1946 to assist Alcoa in efficiently fulfilling the quality needs of those customers for whom all the standard characteristics of a given product are not required for their application and/or for whom certain characteristics are desired at a quality level higher than the standard.

It is not intended here to go into the details of the operation of this system in Aluminum Company of America but rather to describe this tool of quality control.

A Quality Requirement Record is a compilation of significant information concerning the use to which the customer will put the product described therein, the characteristics of importance both from the point of view of the customer's fabricating procedures and from the acceptability of the finished product, and other information useful as a guide in supplying a product suitable for the intended purpose. Figure 1 is a Quality Requirement Record form developed by Alcoa for sheet products. Scanning this form from top to bottom, it will be noted that first, provisions are made for complete information as to Record number, customer, Alcoa product and end product. Following this information, a check list is given for the characteristics which might be retained the same as present in the supplied stock and the nature of the service the finish part is expected to perform. Continuing down the form, attention is directed to the operations which the customer will perform on the material and farther down to the quality factors that are important to the customer in the material as supplied.

There can be established on this form a definite idea of the quality requirements of the customer for sheet material to be used in manufacture of his end product. This information is made available to all the plants of Aluminum Company of America that might be called upon to furnish material for this application for this customer. On all subsequent similar orders from the customer for this application, reference will be made to the assigned Quality Requirement Record number. Thus these desired quality requirements are impressed on the minds of operating supervision each time an order for this application is received, regardless of the plant in the Alcoa organization to which the particular order might be allotted.

In the event that the production of the quality standard outlined in a Quality Requirement Record requires any special processing procedures, the practices to be used are outlined on a complementary form. The form designed by Alcoa for this purpose is called Special Practice Record and is shown in Figure 2.

It will be noted that this form is arranged so that it is identifiable with the applicable Quality Requirement Record and has space provided for outlining the detailed procedures to be followed. As with the Quality

QUALITY REQUIREMENT RECORD
Sheet Products

Date Issued______________ Record No.______________

Alcoa Product______________ Customer______________

End Product______________ Address______________

Order No.________ Item No.________ Date Order Entry________

Description of Alcoa Product:

USE INFORMATION

End product will retain original - Thickness ☐ Length ☐ Finish ☐ Width ☐ Diameter ☐

Chief Use: Structural ☐ Ornamental ☐ Utility ☐

Customer will perform following operations:

Cutting		Working		Joining		Finishing	
Blank	☐	Bend	☐	Braze	☐	Anodize	☐
Machine	☐	Brake Form	☐	Weld		Clean	☐
Rout	☐	Press Form	☐	Spot	☐	Etch-Acid	☐
Saw	☐	Draw	☐	Butt	☐	Etch-Caustic	☐
Shear	☐	Forge	☐	Torch	☐	Paint	☐
Slit	☐	Roll Form	☐	Rivet	☐	Polish	☐
______	☐	Spin	☐	______	☐	Scratch Brush	☐
______	☐	______	☐	______	☐	Finish only One Side	☐

Important quality factors for product as supplied:

Measurable		Metallurgical		Visible	
Diameter	☐	Deep Drawing	☐	Flatness	☐
Length	☐	Freedom from Ears	☐	Freedom from Oil	☐
Squareness	☐	Workability	☐	Freedom from Oil Stains	☐
Straightness	☐	______	☐	Brightness	☐
Thickness	☐	______	☐	Smoothness of Edges	☐
Width	☐			Uniform Appearance	☐
______	☐			Smoothness of Surface	☐

Require only One Good Side ☐ Identify Good Side ☐

Remarks:

Data Supplied by______________

7-24-46 Drawing Attached ☐ Remarks on Opposite Side ☐

Figure 1

SPECIAL PRACTICE RECORD

DATE ISSUED ____________ RECORD NO. ____________

ALCOA PRODUCT ____________ CUSTOMER ____________

END PRODUCT ____________ ADDRESS ____________

Order No. ____________ Item No. ____________ Date Order Entry ____________

Description of Alcoa Produco

Purpose and Details of Special Practice

Copy No. Data Supplied By ____________

Figure 2

Requirement Record, copies of the Special Practice Records are distributed to all Alcoa plants which might fabricate this item so that the same proven procedures will be followed to produce the product to the customer's satisfaction in the most economical manner. Consider the value of the records provided by this system in the event that the use of aluminum should be curtailed in a large number of the applications covered by Quality Requirement and Special Practice Records for an extended period of time as a result of Government allocations. At the time of resumption of normal availability, these records will be ready reference on the "know how" of satisfying the quality needs for the respective applications and should help expedite the efficient change over to production for these normal usages.

One method developed by Alcoa as a means for fulfilling a primary requisite for a successful quality control program, i.e. establishment of the required quality level, has just been described. Two other requisites of primary importance may be classified as process controls and acceptance inspection. Of these latter two, the process controls currently seem to be obtaining the greatest attention as a result of the emphasis that has been put on the necessity of building quality into the product as opposed to the older ideas of inspecting out bad quality. For many years Alcoa has had the philosophy of process control and fortunately, therefore, has not had to adjust its thinking too drastically to adopt the current procedures of Statistical Quality Control. Some of Alcoa's ideas of the mechanics of process control have certainly changed with the advent of the Shewhart Control Chart and these newer tools of process control have been found extremely useful.

Alcoa has utilized for many years frequency distributions and the theory of the normal curve in establishing guaranteed mechanical properties for its products. It is Alcoa's practice in introducing a new product to accumulate mechanical property test data sufficient to give a fairly complete frequency distribution. These distributions are then used as the basis for selecting minimum and/or maximum values to which the product under consideration can be controlled. As time goes on, frequencies for later production are compared with the older data to determine if any significant shift has taken place. Figure 3 is a typical plotting of tensile ultimate and yield strengths used for this purpose. The solid curves represent accumulated test results for the period 1936 - 1940. As a basis of comparison, test results on some forty odd thousand tests made on production of this product during the year of 1940 - 1941 have been superimposed on these curves as open circles. It is interesting to note how well this production coincides with that of previous years with regard to mechanical property distributions.

The previous example indicates that Alcoa has been using statistical approaches to its problems for some long time, as have a large number of other industrial organizations. In recent years, however, with the further development of modern methods of quality control, attention has been focused a little more definitely on the benefits obtainable by application of statistical methods to the control and inspection of quality of aluminum products.

The specific applications to be described herein have been selected with the intent of presenting a varied coverage of some of the products of Alcoa manufacture.

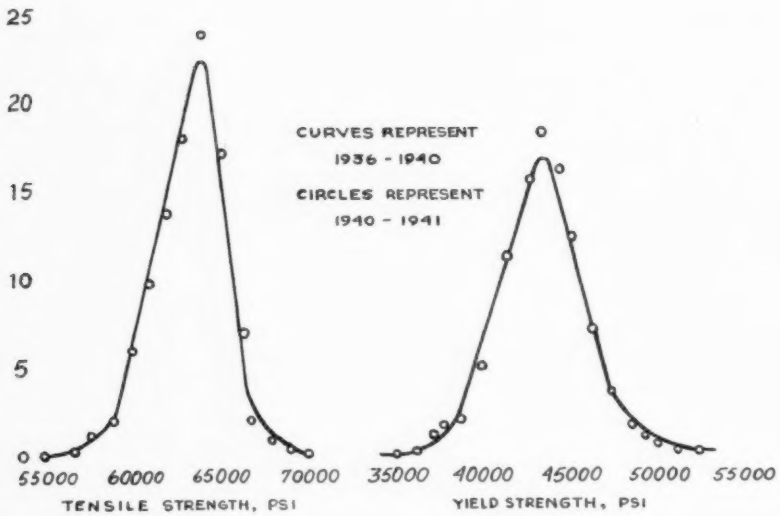


Figure 3

A survey of shipments for the year 1950 broken down to consumer industries showed that about 19 per cent of Alcoa's products went into building industry, 18 per cent into transportation, 8 per cent into power transmission conductors, 8 per cent into household appliances, 6 per cent into cooking utensils, 4 per cent into machinery and the remainder to other uses. Although the above shows that a large percentage of aluminum products go into the building and transportation industries, a fairly good portion is used in power transmission lines. For these long spans of transmission lines, Alcoa supplies in addition to cable, numerous accessories that play an important part in the successful life of such lines. Two such accessory items are the Stockbridge Damper and Tapered Armor Rods.

Encouraging success has been experienced in the application of control charts to the production control of these items. The Stockbridge Damper is shown as used on a transmission line in Figure 4. Its purpose, as indicated by its name, is to damp out vibration of the line and thus reduce the liability of fatigue failure. Figure 5 shows the components of a Stockbridge Damper and the assembly. The collet in the center of this picture is used to attach the weights securely to either end of the resilient member or length of cable shown at the extreme left. The primary taper of this collet and the taper of the hole in the weight are of utmost importance if the weights are to be held securely in the assembly. It is a serious matter to have these weights dropping off an overhead cable after they have been in service. The weights on a damper of size commonly used, for example, weigh 7 pounds each. In addition, the fit of

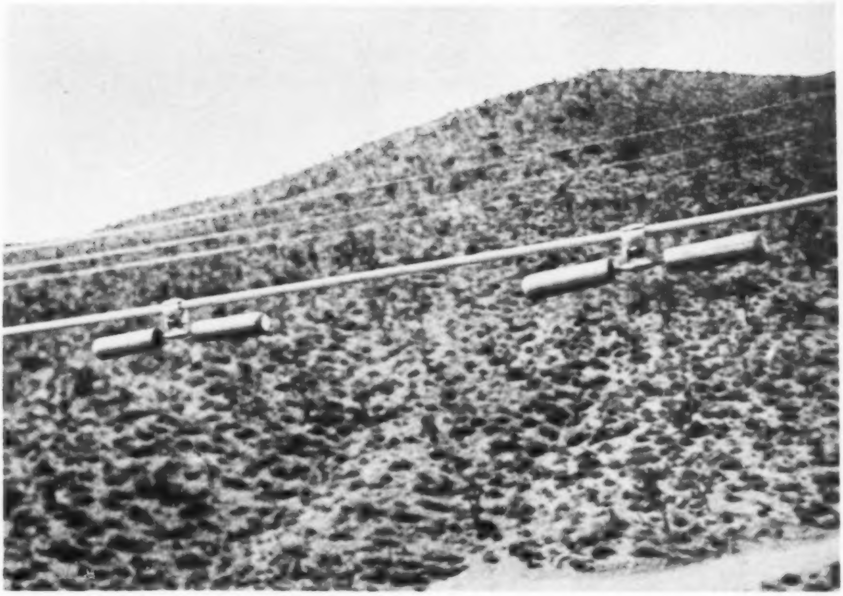


Figure 4

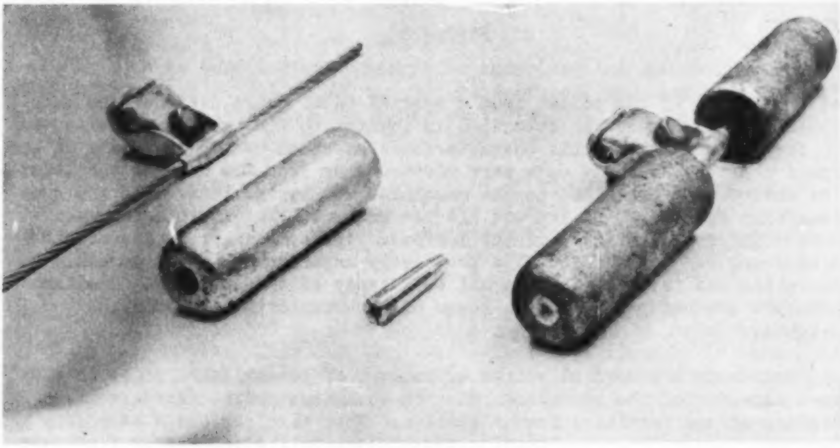


Figure 5

the collet and weight must be such as to minimize projection of the end of the collet beyond the end of the weight. Such projection can result in corona effects which are undesirable because of their interference with

radio reception,

Figure 6 is a typical control chart used on the taper of one size of collet for such an assembly. The measurement made is that of the height

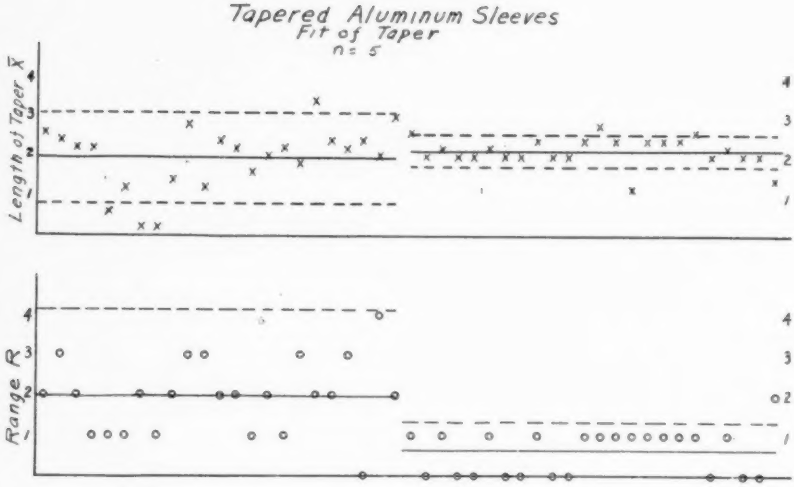


Figure 6

of projection of the collet from a special taper gauge designed for this application. Particular attention is invited to the improvement effected in the variability of this characteristic as shown by the narrowing of the range chart. The early data were plotted away from the machine and later the charts were explained to the machinist who became interested and successfully endeavored to improve his performance. The improvement made here entirely as a result of the increased operator interest has considerably reduced the difficulties previously experienced in the assembly operation and improved the overall efficiency of the assembly. Similar controls are being used on the taper of the counterpart hole in the weights.

Armor rods are used at points of support of transmission lines to prevent abrasion of the conductors at such locations and to decrease the bending stress resulting from vibration. They also perform a secondary function in damping out vibration and protecting the cable from flashover burns. Tapered armor rods are lengths of aluminum rod machined to a given taper calculated to be most efficient in performing the function of blending the nest of rods with the cable. Figure 7 shows tapered armor rods as installed on a transmission line. In addition to the importance of proper taper in the functioning of the rods, it can readily be recognized that the ease of clamping such assembly, especially when working on

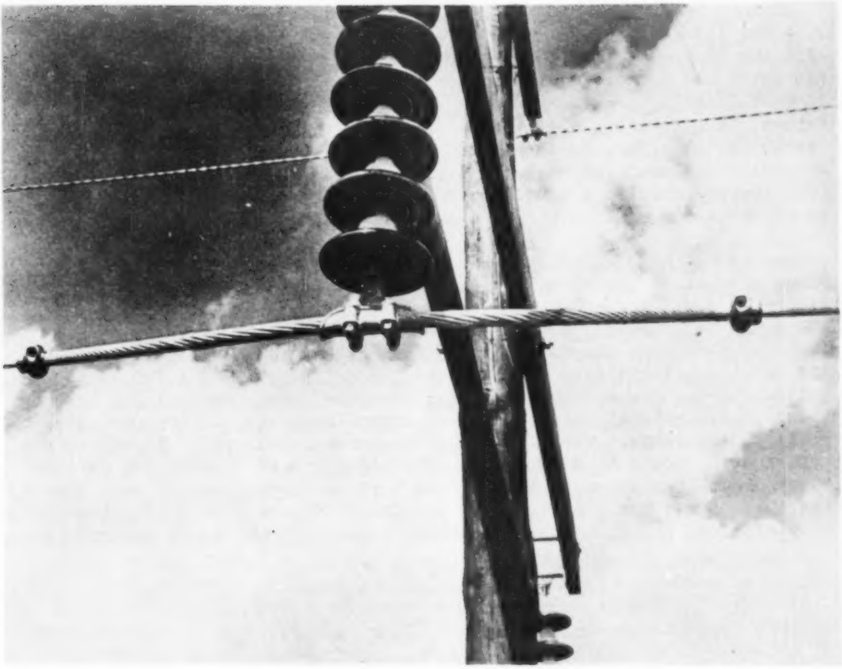


Figure 7

a hot line as is sometimes necessary, is important and is contingent on a properly nested condition at the juncture of the rods and the cable. The effort made in studying and subsequently controlling the operation of machine tapering rods of this type have been well repaid.

In the early part of 1950, considerable difficulty was being experienced in maintaining desired consistency of taper on these machine tapered rods. With the hope of rectifying this situation, a program was introduced to study the capabilities of producing a more uniform taper.

It was decided first to establish an additional tolerance to be held at a location two inches in from the ends of the rods to supplement existing tolerances. This location was selected because it is here that the clamps are normally applied and difficulty in assembly was being experienced. An attempt was then made to hold this new tolerance in production but the results were not encouraging. Even after the tapering machines were overhauled it was found that excessive scrap and a dropped production rate resulted from attempting to maintain the tolerance at the two inch location. It was then decided to try the use of control charts on the operation. Five samples from each lathe were taken each hour and $\bar{X}$ and R charts plotted for the diameter two inches in from each end of the rods. Different charts were plotted for each size of rod produced on each machine. There being seven machines, as many as fourteen charts were maintained at one time and in covering all the sizes, the complete task involved keeping a total of 280 charts.

Without going into the detailed step by step accomplishments effected with the aid of these charts, the story on this item can be concluded with the statement that production on this operation has increased, scrap has decreased and cost has been lowered. At the same time an improved product is being produced because of the closer tolerances being maintained. The charts are effective in this operation because of their psychological effect on the lathe operators, as well as their usefulness in predicting need for adjustment or maintenance. In the latter case, they thereby provide a basis for more efficient scheduling of repairs so as to reduce to a minimum the interference with production.

One of the more interesting fabricating processes performed on aluminum is that of impact extrusion. In this process a slug of metal is seated in a die and a punch made to strike it with an impact load causing the metal to literally squirt up around the periphery of the punch to form a can or tube shape. It is by this method that collapsible tubes are made for diversified applications including containers for tooth paste, shaving cream, pharmaceutical products, etc. Control charts have aided in dimensional control of such operations. In the interest of satisfying a request for closer than commercial tolerance, it was agreed that a study would be made of the practicability of holding the desired tolerance on the average wall thickness in the area from the open end of the tube inward for a distance of one inch. Figure 8 shows the improvement effected in this case. The first section of the chart represents

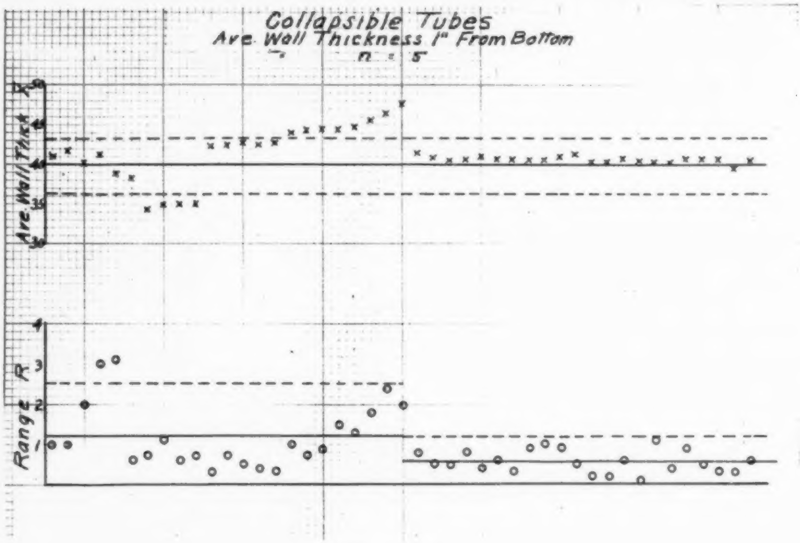


Figure 8

preliminary data accumulated under normal production of this part to commercial standard tolerances. The set-up man on this machine was then told to do the best he could to maintain the closer tolerance and was instructed to a very limited extent concerning the control charts which were being maintained as a running record of the dimensional control being ob-

tained. The latter section of this chart shows the $\bar{X}$, R charting of the average wall thickness for a period thereafter. The control limits are modified limits within which averages of five must fall to indicate conformance with the desired tolerance. Measurements on this application are made with an air gauge and the average for each tube is taken as the mean of the highest and lowest value obtained in scanning the area to be controlled. This job is run intermittently as orders are received and it has been possible to maintain equally good control on each production run as is exhibited by this chart.

Another aluminum alloy item of popular acquaintance is the permanent mold automotive piston. Large quantities of these are supplied to the industry in the rough machined condition. In view of the quantities involved and the numerous dimensional requirements on this product, the rough machining operation was singled out as a possible fruitful place to apply some modern process control methods. With the characteristics to be controlled in the machining operation being primarily dimensional, a program of control charting was instituted. However, although useful information was developed as a result of maintaining charts on each machine for each type of piston being produced, the burden of this charting seemed excessive. For each piston, such dimensions as outside diameter, head thickness and squareness, concentricity, inside diameter at skirt end, pin hole to head distance, etc. had to be maintained within certain tolerances. The number of charts required for these dimensions multiplied by the number of machines and the number of different types of pistons supplied was considered prohibitive. With the background of this charting experience, however, it was decided that good control could be effected by use of an attribute sampling plan. An inspection plan was set up on the basis of relatively small lot sizes consisting of consecutive production from a given machine. Inspection is conducted on the machine line floor as soon the number of pistons comprising the lot has been machined. Tabulations of failure to meet the individual dimensional requirements are maintained and the failure of any lot to pass the sampling plan is immediately brought to the attention of the foreman or set-up man. Details concerning the nonconforming dimension are furnished to assist in determining what corrective action should be taken. Acceptable and rejectable lots are tagged accordingly with the result that no further inspection for dimensions is required of the acceptable lots, but rejectable lots are detailed in final inspection for the particular dimension found outside of tolerance under the sampling plan. This plan has proved to be efficient from an inspection cost viewpoint but even more outstanding because of its influence in reducing the number of off tolerance pistons produced at the machine. Table I gives a tabulation of the monthly machining process average estimated from the sample results for a period of time after installation of this in process sampling inspection. Distinction is not made in this tabulation between reworkable items and scrap items.

For processes in which data have shown a rather well established variability of a given characteristic to exist, efficient inspection by variables plans can be easily developed. A paper by Dr. Edwin G. Olds (1) incited the investigation and use of this type of approach in the inspection of hardness of certain classes of aluminum alloy forgings. The details of this type of plan are available in the reference. In general, the plan provides that the values obtained in inspecting the required sample be averaged and that the decision to accept or reject for detailing

Table I

Month	% Rejectable (Outside Tolerance)
January	8.7
February	9.0
March	8.0
April	4.8
May	4.6
June	2.5
July	2.3

be based on the relationship of the average obtained to that of a statistically calculated value derived from the guarantee and the accepted risks. It is highly desirable that a range or standard deviation chart be kept concurrently on the test results as a check on the continued operation within the standard deviation on which the plan is calculated. It is the opinion of the author that the psychological effect on the Inspector of the necessity of his recording and using his individual readings in this manner to make a decision is all in favor of his being more careful and precise in taking those readings. Where the decision is one of acceptance or rejection of an individual item based on the result of a certain measurement or observation, there is an all too human tendency to make rapid and sometimes inaccurate readings. On the other hand, when the disposal of the entire lot depends on the accuracy of each individual reading as reflected in the calculated value and the variability of these readings as indicated by the range or standard deviation chart, the natural tendency is to be more precise.

One of the early applications made of statistical sampling inspection by Alcoa was in the inspection of sheet circles. Large tonnages of aluminum sheet are sold as blanked discs to customers who prefer to have the aluminum producer perform this first operation in the fabrication of their end product. In a sheet and plate mill, this product seemed to be the logical starting point for using statistical sampling methods because of the relative ease of handling to obtain the desired sample. A single sampling plan was first instituted for this purpose several years ago after preliminary investigations to determine the reliability of a sample, taken not strictly in a random manner, in detecting a sub standard quality lot. Sheet circles normally arrive on the inspection floor stacked on skids, the number of stacks per skid depending on the diameter of the circle. A lot might consist of one or more skids. The most practical manner of taking the sample, naturally, is to take a representative number from each stack on each skid comprising the lot. While this is not strictly a random sample, it is far closer to a random sample than might appear if it is recognized that these circles are handled and as a result are shuffled to a considerable extent several times before inspection. As the circles come from the blanking press, they are stacked at random on skids to be conveyed to the annealing furnace. Here they are again handled in a similarly non-patterned manner as they are removed from the skids for placement in a conveyor type annealing furnace. At the exit end of this furnace, the circles are again placed on the skids in a random manner in building up the stacks from the tops of which the samples are taken for inspection. Investigations have demonstrated that this sampling procedure is representative. Figure 9 is a picture of a lot of circles

being inspected under this system. The Inspector has taken an equal

Figure 9

number of circles from each stack shown on the skid and is examining the sample.

Progressing from this single sampling plan, there has been developed a very efficient system of multiple sampling as the annealed circles are taken from the conveyor of the annealing furnace. With this system a series of samples is taken at somewhat regular intervals during the annealing operation of each lot of circles, as they are being removed from the furnace. Figure 10 shows the exit end of a wicket annealing furnace. The two girls in the picture have the primary task of removing the circles and stacking them for subsequent packing and shipping. The Inspector is identifiable by the micrometer in his hand. The plan used is set up on the basis of multiple samples of twenty circles each. In operation, the Inspector will take twenty circles with representation across the width of the conveyor, evaluate these circles and record under the proper classification any defectives found. This procedure is repeated at intervals until evidence of acceptability or rejectability is obtained in accordance with the plan.

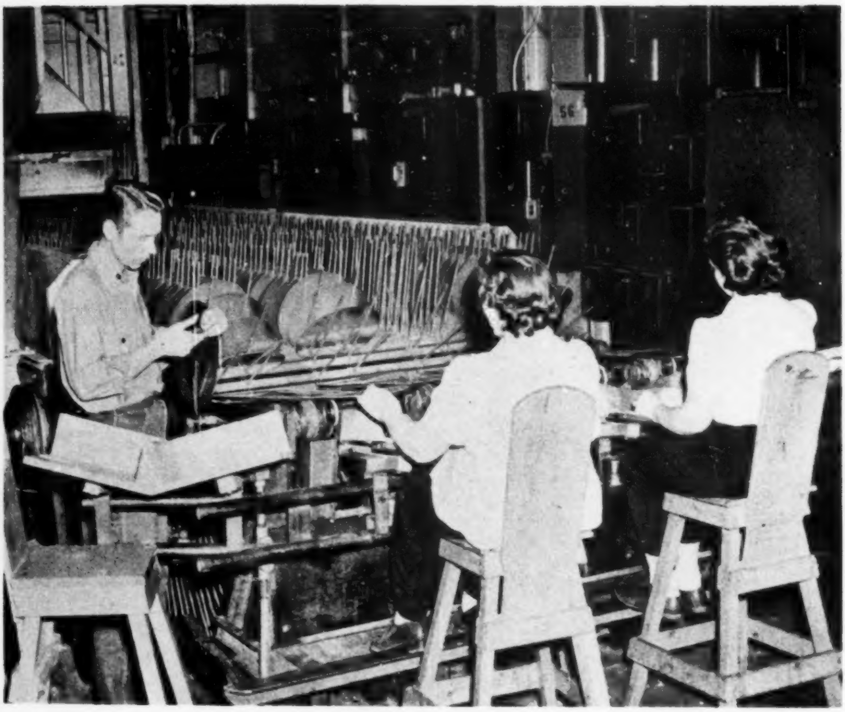


Figure 10

If there is evidence of rejectability or if there is not evidence of acceptability by the time the lot has passed through the annealing furnace, the material is set aside for detailing. Lots proven acceptable by the sampling plan are removed directly from the annealing furnace to be packed and shipped. This plan has the added advantage of requiring less material handling than the single sampling plan with the result that there is less difficulty from scratches caused thereby.

Based on the results of sampling inspection of sheet circles, per cent defective control charts are used periodically to obtain a picture of the level of quality with regard to total defects and individual defects. Figure 11 shows representative charts of this type. It can be seen from this series of charts that scratches were the greatest cause for rejection of the material represented.

With the introduction of induction heating of cast to length ingots, difficulty was being experienced because of variation in weight of the ingot. This problem was largely one of mass effect where under the established cycle too large a piece failed to heat to the required temperature and too small a piece heated excessively. It was determined that the most of this variation was attributable to length and, therefore, this dimension was put on X and R chart control. Figure 12 is a panorama of three stages of this application. The first section represents the early charting and shows the process to be in control. The ordinate scale is

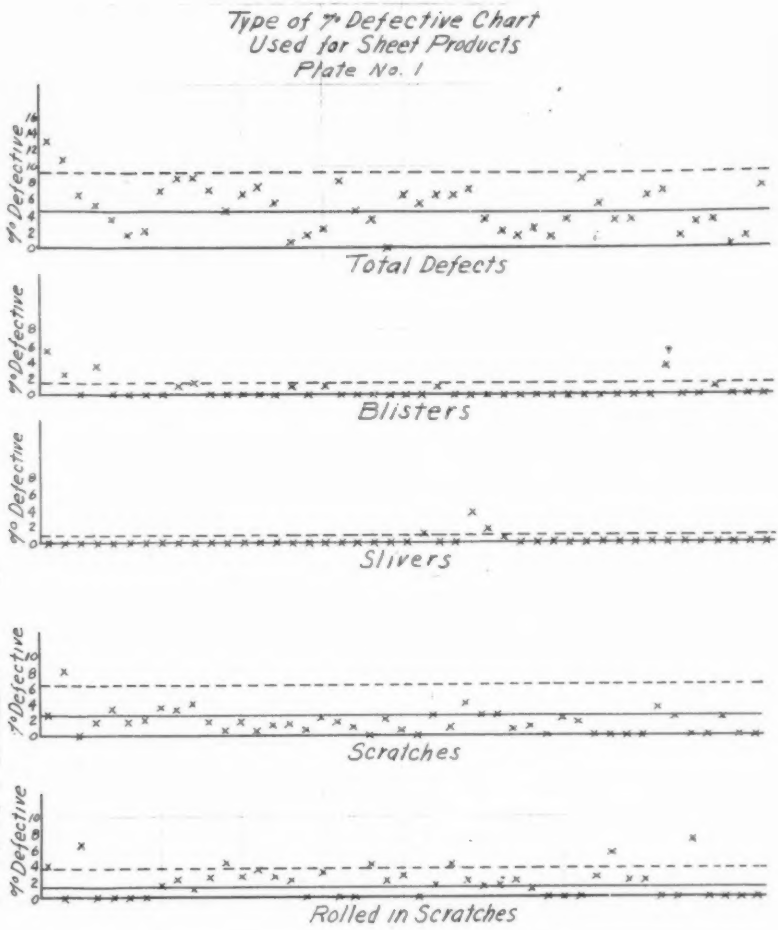


Figure 11

average length of five ingots above the minimum desired length. This chart indicates that the process is in control but that the level of control is not sufficiently good to meet the specified tolerance. Engineering assistance was sought, therefore, and a gauge was perfected to assist in maintaining the desired length.

The center section of this chart represents the next cast of ingots

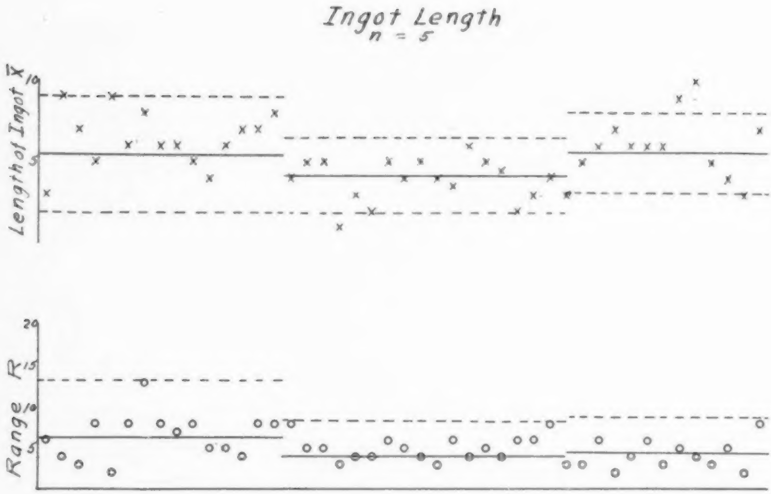


Figure 12

poured with the help of the newly designed gauge and of the control charts posted for the information of the operating personnel. It will be noted that considerable improvement has been effected. In the last section, however, it was decided as an experiment not to post the control charts but merely to take the readings and post them in tabular form without any indicated warning limits. It is interesting to see how the level of the production changed when the charts were removed. The charts are now routine on this application and better uniformity is being obtained in fabrication as a result of more consistent heating.

In plant operations, it is sometimes found that a large part of the benefit of control charts can be obtained without actually maintaining such charts on the floor but by giving the operating people a "rule of the thumb" method of determining the need for corrective action for the pertinent process. This approach was resorted to as a control on the scalping of ingot for magnesium alloy sheet fabrication. This application is mentioned here because of the general applicability of such an approach where there might not be justification for keeping charts but where a scientific "rule of thumb" is desired. In this operation, it had been the practice to weigh the group of ingots before and after scalping to check the amount of surface metal being removed. Although a nominal thickness to be removed was established, the problem was one of deciding when the deviation from the desired nominal was considered excessive.

A statistical study of the process was made to determine its standard deviation. From the results of this study, limits were calculated for the total weight of scalpings to be expected under normal chance variations based on the desired depth of cut and the various sample sizes within which a load of ingots being processed would normally fall. In this particular application the number of ingots comprising the lot covered from fifteen to twenty. Tables such as the example shown in Table II were prepared for each size of ingot being used.

Table II

No. of Ingots in load	Average Total Scalp Loss Pounds	Permissible Limits max.	min.
20	470	501	439
19	447	477	417
18	423	452	394
17	400	428	372
16	376	403	349
15	353	380	326

These tables were made available to the operating personnel and have been favorably received and used as a guide in controlling the scalping operation. Although some of the advantages to be obtained by the use of charts such as early detection of trends, the possibilities of improving the process by following through on indications of improvements, etc. are not as evident under this approach; it does, however, serve a useful purpose. Such approach may also be used as a wedge to the eventual use of charts where a gradual selling job is required.

With an increasing appreciation of the statistical method of evaluating inherent process variability, Alcoa has considered it desirable to review current standard tolerances for wrought aluminum products to ascertain their compatibility with natural tolerance capabilities under present production methods. Existing tolerances in the aluminum industry, as in other industries, are not necessarily the result of sound statistical treatment of production results. They have developed over a long period of time and have been influenced by considerations other than a factual knowledge of process capability. To arrive at more representative tolerances or to develop statistical support of existing tolerance as the case may be, a program for studying dimensional variability has been undertaken. In view of the fact that such a program could very well lead to discouragement if all products were surveyed simultaneously, it was decided to concentrate first on gauge variation in sheet and plate products. This in itself has developed into a major investigation, but it is hoped that the results when they are finally analyzed will justify the effort.

The fact that a certain size sheet product might be made by rolling to width or by rolling to multiple width and slitting influences the natural tolerance of the finished product as do other factors such as the particular type mill on which the sheet is rolled. In the program now being conducted, all the factors that might affect the gauge variation are being given consideration. The data for this study are being obtained

in the form of continuous gauge recordings of complete coils of sheet and by gauge measurements on random samples of numerous lots of material. Final analysis of these data might well result in certain changes in established standard tolerances, the tolerances finally adopted, however, will be based primarily on process capabilities.

The applications discussed herein were selected as an assortment depicting the diversity of use to which Alcoa has successfully applied modern quality control techniques in its operations. They do not represent any particularly new principles. This paper was prepared primarily with the hope that these actual experiences might be of interest and that from them might come encouragement to others to investigate the possibility of obtaining similar benefits.

Although quantitatively the utilization of control charts and sampling plans in Alcoa's operations as of today is not outstanding, it is felt that the success of the applications that have been made definitely points to many more benefits yet to be derived from an ever extending use of the principles of industrial statistics.

References

(1) Edwin G. Olds, Acceptance Sampling By Variables, ASQC Conference Papers, 1947.

REDUCING THE EFFECT OF PROCESS AND TESTING VARIABILITIES

Robert M. Hofstead
Bristol Laboratories

Death, taxes, and variability are the three certainties in life. Medical thinking is concerned with the first, political thinking is concerned with the second, while statistical thinking is concerned with the certainty of variability.

Most of the effort, at least in medical and statistical thinking, has been to seek out and eliminate, as much as possible, the causes of their respective anxieties. It is the purpose of this paper to present a statistical technique for reducing the effect of variability, not the variability pattern itself. The justification for this approach can be explained from a production point of view. The two benefits: (1) greater production efficiency through less reoperation and (2) lower unit cost by safely reducing overfill, are derived from either approach. However, reducing the variability is generally time-consuming. The benefits are effective immediately if the effect of variability is reduced. While investigations are taking place to reduce the statistically ascertained variabilities, production output can continue at an increased rate with lower unit cost.

Example I

This is a penicillin batching operation. Chemical assay determinations are made on the bulk penicillin which, along with other ingredients, makes up the final product. The final product has a lower specification limit for potency of 10% below label claim. Although the manufacturer is allowed 10% below label claim by the F. D. A., the Bristol quality policy is to place their lower 2σ limit on label claim. The upper limit of potency is governed solely by economy. The higher the potency above label claim, the higher the unit cost of manufacture. Greater dosage is not toxic, nor of great benefit. If the pre-fill chemical assay indicates that the requirements just mentioned have been met satisfactorily, the product is filled into vials. The filled material is then chemically assayed by both the F. D. A. and the manufacturer. If the potency requirements are met, the F. D. A. releases the material for distribution. There are, of course, many other requirements to be met on this product: volume fill, sterility, stability, performance, etc.. We shall be dealing here only with the potency per milliliter.

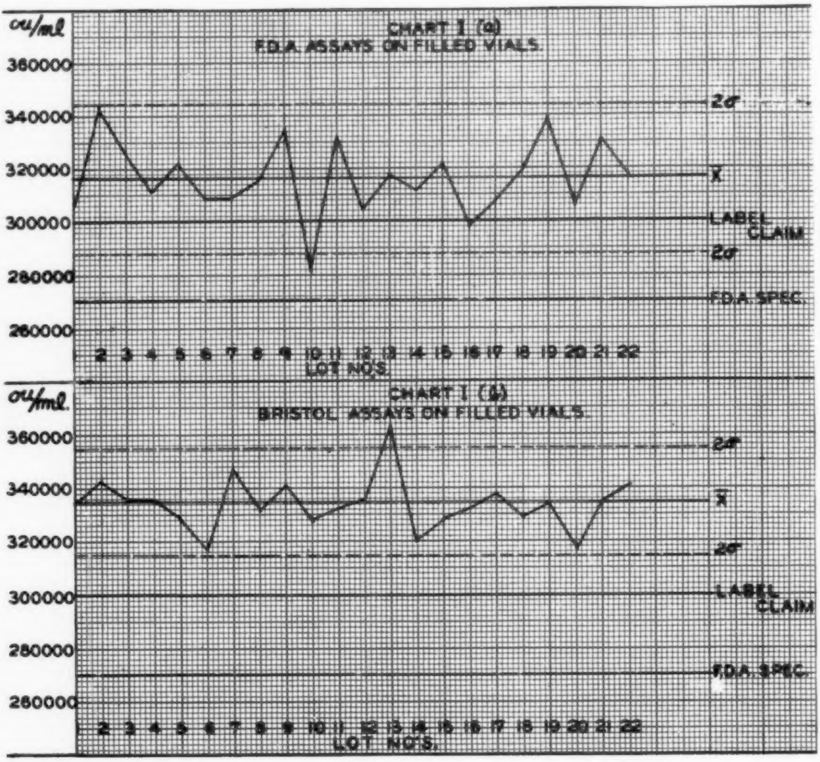
Thus, the sources of variability in the determination of the potency of the final product are:

(1) volumes and weighings of all ingredients
(2) initial chemical assay on the bulk penicillin
(3) pre-fill chemical assay on the batched product
(4) final chemical assay on the final product
(5) sampling variability.

The total effect of these sources can best be shown by Chart I(a) which is the F. D. A. assays on filled vials for 22 lots, and Chart I(b) which is the Bristol assays on filled vials for the same 22 lots.

Table I

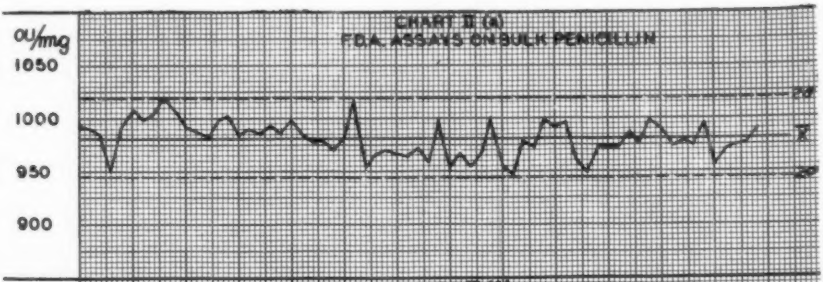
Chart I(a)			Chart I(b)		
F. D. A. (cu./ml.)			Bristol (cu./ml.)		
$\bar{X}$	σ	$\sigma/\bar{X}$	$\bar{X}$	σ	$\sigma/\bar{X}$
316,300	14,160	4.5%	334,400	10,100	3.0%

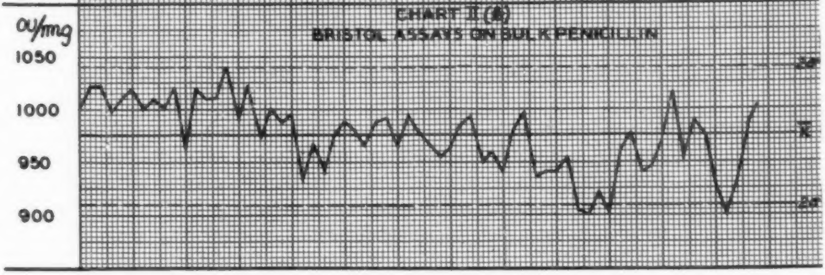


The variability of the F. D. A. is greater than that for Bristol and may approach significance. The difference in averages also appears to approach significance, although possibly qualified because of the variability difference. The question we are concerned with is: from what source or sources does most of the variability arise in both laboratories? If the source or sources of variability can be ascertained and the effect of this variability reduced, (1) the average potency for batching could be lowered and (2) the necessity for reoperation could be eliminated, i. e. either adding more vehicle to dilute, or adding more penicillin to increase the units per milliliter. The variability which the chemical assay contributes to the total variability is at a minimum. Consequently, the first step is to study the bulk penicillin picture. The potency of the bulk penicillin determines the amount of penicillin added to each batch. Chart II(a) shows the F. D. A. assays on bulk penicillin for 65 lots and Chart II(b) shows the Bristol assays on bulk penicillin for the same 65 lots.

Table II

Chart II(a)			Chart II(b)		
F. D. A. (ou./mg.)			Bristol (ou./mg.)		
$\bar{X}$	σ	$\sigma/\bar{X}$	$\bar{X}$	σ	$\sigma/\bar{X}$
981.3	18.8	1.9%	976.1	32.7	3.4%





This indicates the F. D. A. and Bristol averages for bulk penicillin during this period are at the same level. However, the variability of the Bristol potency assay is significantly higher than the F. D. A. potency assay (P = .002). Production cannot batch by the F. D. A. bulk assay. The delay involved in waiting for their results would be costly. Consequently, the Bristol bulk potency assay is used for batching. Production, as the result, merely pursues Bristol assay variability in mixing batches. When the Bristol assay underestimated the bulk potency, production initially added too much penicillin, and the lot required rebatching by dilution with gel. For example: suppose the true bulk penicillin potency is 985 ou./mg.. The Bristol assay says the potency is 950 ou./mg.. If the batching formula calls for 300,000 ou./ml., production would add 3.68% too much penicillin, and the final potency per milliliter would be 311,040 ou./ml. instead of 300,000 ou./ml..

$$985 \div 950 = 103.68\%$$

$$103.68\% \times 300{,}000 = 311{,}040 \text{ ou./ml.}$$

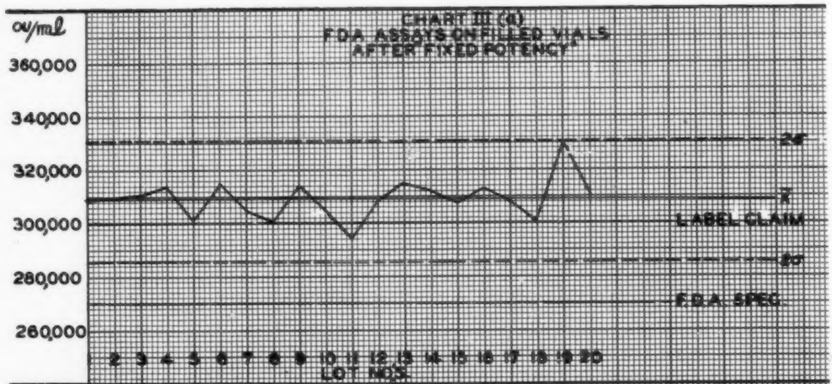
When the Bristol assay overestimated the bulk potency, production initially added too little penicillin, and the lot required rebatching by addition of more penicillin to increase the final potency per milliliter. This is just the reverse of the example quoted above.

To reduce the effect of the variability shown above, we can make use of a "fixed potency" for all bulk penicillin. A "fixed potency" will reduce the lot to lot variability of the filled vials. The potency overfill can then be lowered, and the lower 2σ control limit will still remain above label claim. If we assume all bulk penicillin potencies at 1000 ou./mg., we would expect to decrease the average potency of the final vials approximately 2%. The reason for this is shown in Chart II(a) and Chart II(b). The average potency for the 65 lots of bulk penicillin is 981 ou./mg. by F. D. A. tests and 976 ou./mg. by Bristol tests. When a 1000 ou./mg. bulk potency is assumed, it is approximately 2% higher than the actual level and averagely 2% less penicillin will be added in the batching.

Chart III(a) shows what occurred in 20 lots, according to the F. D. A. assay, after batches were prepared using a fixed bulk potency of 1000 ou./mg.. Chart III(b) shows what occurred in the same 20 lots, according to the Bristol assay, after batches were prepared using a fixed bulk potency of 1000 ou./mg..

Table III

Chart III(a)			Chart III(b)		
F. D. A. (ou./ml.)			Bristol (ou./ml.)		
$\bar{X}$	σ	$\sigma/\bar{X}$	$\bar{X}$	σ	$\sigma/\bar{X}$
308,300	11,400	3.7%	327,000	7,700	2.4%



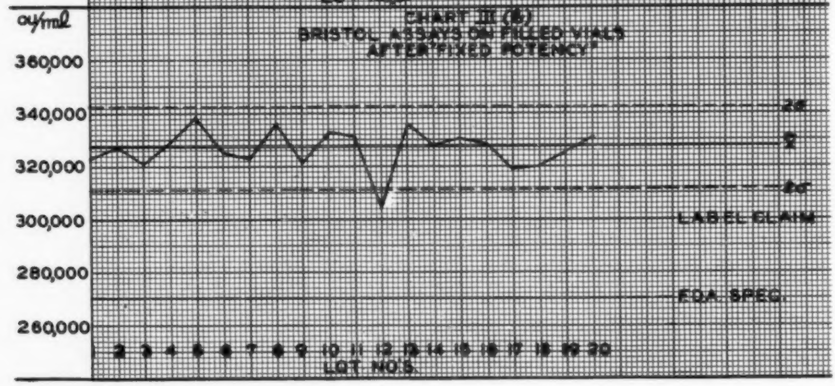


Table IV records the effect of using a "fixed potency" of 1000 ou./mg. for the bulk penicillin potency in batching. This table combines Table I with Table III.

Table IV

Finished Vials	F. D. A. (ou./ml.)			Bristol (ou./ml.)		
for Period	$\bar{X}$	σ	$\sigma/\bar{X}$	$\bar{X}$	σ	$\sigma/\bar{X}$
Prior to "fixed potency"	316,300	14,160	4.5%	334,400	10,100	3.0%
Since "fixed potency"	308,300	11,400	3.7%	327,000	7,700	2.4%

The F. D. A. assay dropped 8,000 ou./ml., and the Bristol assay dropped

7,400 cu./ml.. The F. D. A. standard deviation decreased 18%, and the Bristol standard deviation decreased 20%. As measured by either assay, the saving through this reduction represents approximately 2.4% of the bulk penicillin consumed per batch prepared. The saving gained by less reoperation is more difficult to determine; however, such a saving is certainly not negligible.

PROBLEMS OF RECEIVING INSPECTION AND THE ASSEMBLY LINE

W.H. Smith
Ford Motor Company

Some of what I will say this afternoon is very likely to be "old hat" to a number of you in this audience. The Quality Control techniques we will be discussing are certainly not new to anyone who is conversant with standard methods for Statistical Quality Control.

But our experiences, as reflected in a few problems and case studies may be stimulating, inasmuch as they come from high volume operations where even the smallest quality improvement pays off in a very substantial way.

Since Nelson Meagley is going to tell you about Willys-Overland's Quality Control program on the Jeep assembly line, I shall restrict myself to the receiving inspection of incoming parts and the Quality Control of sub-assemblies supplying our final assembly lines.

(Figure #1 - Receiving Inspection Flow System)

This slide shows, in a very elementary fashion, how Quality Control fits into the flow system between the receiving docks and the manufacturing departments. Inasmuch as Quality Control is a preventive program, it should be noted that receiving inspection, if it is to be most effective, must take place before parts and materials reach the storage area. This is found to be one of the most critical decisions facing a newly organized Quality Control program: not only must a sampling plan be instituted on receiving parts, but there may also have to be some pretty drastic changes with regard to the flow of stock and the storing of uninspected shipments in the stock rooms. We hold to the principle that materials should be accepted into stores in the full sense of the word "accepted." This means that they should not be inspected in transit from the stock room to the point of use — or worse still, in direct transit from the receiving dock to the point of use. Many advantages were found in the "Bond Room" set-up which so many of us used in Defense Jobs during World War II, and these lessons should not be forgotten.

A particular advantage to making your quality determinations before storing is found in the promptness with which your suppliers can be urged to solve rising quality problems. If the receiving inspections are to serve the two-fold purposes of quality protection and quality improvement, too much emphasis can not be laid on the prompt inspection of shipments upon receival. Another important consideration is that materials should be handled in the stock room on a "first in, first out" basis. Without such a provision, it is impossible to adequately handle campaign corrections or design changes with which even the best quality control system will occasionally be faced.

Let's study the figure a little more to see what can and does happen with a poorly organized receiving program. The upper flow chart depicts the kind of hap-hazard system which almost invariably results from lack of a plan <u>and a desire</u> for Quality Control. Incoming stock can go in any of a number of avenues, most of which result in leakage of defective parts to the manufacturing area — or even in the outright misdirection of entire rejected shipments to manufacturing. Any bin of parts becomes fair prey, regardless of its location and quality disposition, for the

fellow in the manufacturing department whose job happens to be in desperate shape for lack of material. And believe me, as long as the pallets or boxes are not nailed to the floor, that is exactly what happens under such a system.

Inspection, in these circumstances, can only be weakly effective at best, and many of the inspections, however capably performed, are futile from the standpoint of furnishing sound materials to the manufacturing department.

Now let us say that the condition represented as "good" in the figure has been achieved. Observe that there is no leakage, and that inspected shipments can go in only two directions, either to "OK stock storage" or to "rejected stock storage." If parts are on critical shortage, and the supplier nevertheless requires that any rejected shipments be returned, then it may be economical for the consumer to sort or to repair at his own expense in order to keep his jobs running. And even when parts are not on shortage, the supplier may for purposes of economy propose that rejected shipments be sorted or repaired at his own expense, rather than have them shipped back for credit. Arrangements of this kind generally work out to mutual advantage, but they must take place under a tight system of control in which reinspection or sortings result finally in the forwarding of sound materials to OK stock storage.

It is well, also, to consider the nature of the inventory you have on hand under the "good" and "poor" systems depicted here. Under the latter, a very sizable portion of the inventory is of undetermined quality. The manufacturing department is likely to be working a good share of the time on a hand to mouth basis with inspection, since a large part of the float is literally floating instead of standing ready in stock storage for use. If incoming quality on a part goes seriously bad, there is likihood that the part goes automatically on shortage, since a bank of acceptable stock is not available to see the manufacturing department through. But under the system depicted as "good," quality emergencies of reasonable proportion can be readily coped with because the inventory is so largely made up of inspected and dispositioned shipments.

Of course it is easy for someone to stand up here and talk of the ideal situation as long as he does not have to bother himself about putting the principles to work. Our two and a half year old program for improved Quality Control at Ford has still to reach full maturity. We still have growing pains in abundance. But some amazing progress has been had in our large receiving locations, more than enough to prove that the goal of improved receiving is a most worthwhile thing to go after. A little later on I will give you some before and after figures on one of our receiving inspection jobs, but first I want to talk about Acceptance Sampling.

Acceptance Sampling generally has to do with receiving inspection, as many of you know, though the same method may also be used as a summary check on end product shipment quality.

If your company was anything like ours in years gone by, its receiving inspection varied in degree between two wide extremes. Some incoming shipments were regularly inspected 100% at receiving, because there was a history of poor quality on the parts. That was one extreme, and at the other extreme was only the verification that the contents of the shipment were properly identified on the shipment label. Generally

though, receiving inspection fell some place between these extremes. Standard practice in some firms, for instance, continues to be ten pieces per shipment, regardless of how large or small the shipment might be.

(Figure #2 - Marbles Demonstration)

This figure shows a group of our vendor representatives witnessing a demonstration of the risks involved in such a standard sample plan. The box contains 1000 marbles, 50 of which are red or defective, and 950 white, or acceptable. This, then, represents a lot of 1000 pieces which is exactly 5% defective. Our visitors found out, somewhat to their surprise, that repeated ten piece samples contained not a single defective on more than half of the tries. In other words, a good majority of the time, such a 5% defective lot would be passed by the inspector if he examined only ten pieces. There would actually be a greater chance of rejecting if he passed judgement by the flip of a coin — heads we keep the shipment, tails we send it back.

Other firms, recognizing that the sample size should in some measure be dependent on shipment size, use a flat 5% or 10% sampling inspection plan. This is evidently done in the mistaken belief that every shipment is thus subjected to an equally rigid testing, regardless of its size.

(Figure #3 - Table on Sampling Risks)

A long look at this method reveals some interesting things about varying risks. In fact, they are more than interesting -- they are staggering. Figure #3 is a modification of a chart which appeared in the book titled "A Basic Training Manual on Statistical Quality Control." It is used by the kind permission of the authors, Rudolph Freedman and Joseph Movshin, who are associated with the St. Louis Society for Quality Control.

In this case, we have three shipments of varying sizes, each of which is exactly 5% defective and each of which is submitted to a 10% sampling inspection. We are going to reject the shipment if we find even one defective in the sample, since that is how many of these 10% plans work.

The amazing results of a series of such inspections are shown in the third column. Observe that the risks of accepting rejectable lots are ridiculously different, comparing the largest lot to the smallest. If your supplier ships in lots of a thousand he gets knocked down 99 times in a hundred for a 5% defective shipment. But if he ships in lots of 100 pieces he only gets caught 40 times in a hundred. I would hate to have to justify this sampling plan to three suppliers, each of whom for a particular and unalterable reason regularly shipped in only one of the lot sizes shown here.

The inconsistency of these two sampling methods, flat ten piece and flat ten percent, stems from the fact that neither approach recognizes the risks which are involved to some calculable degree in any sampling plan, including the best. Even a well regulated flow system, such as that which we discussed a moment ago, makes only a meager contribution to Quality Control if a proven sound sampling technique is not used to check the shipments through.

True Acceptance Sampling is only a more intelligent approach to this same matter of making quality judgements on the basis of examining representative samples. Risks are calculated so that inspections made ac-

cording to the plan will with predictable certainty be good guides for the judgement of incoming shipments. Acceptance Sampling, since it is based on known risks, is an inspection method for attaining the maximum in quality assurance with a minimum in inspection effort. We all know that you can't afford to employ 100% inspection on every piece out of every incoming shipment. And since you cannot afford 100% inspection, the compromise is actually one of quality assurance versus inspection effort. Acceptance Sampling is designed to balance these so that the most economical sampling is made which is consistent both with the kind of quality you feel you ought to have and with the risks you can afford to take in determining whether or not the desired degree of quality is being met.

It comes as a rude surprise to many who are not in this kind of work to know that a manufacturer, while he desires perfection in his incoming shipments, may feel that he can afford to live with shipments which are on the average as much as 2% defective. The philosophy of Acceptance Sampling has to do with a realism which says that I can't get perfection from my suppliers; neither can I afford to screen out each and every defective. I must therefore employ an inspection method which will require the least inspection effort in my plant to ensure that my suppliers do not with any frequency exceed the amount of defectiveness I can afford, in the long run, to absorb in successive shipments.

Maybe this level of defectiveness is 2% and maybe it is ½%, depending on the importance of the particular quality characteristics and parts involved. But at any rate the decision has to be made. If you can't bring yourself to this decision, then you can't enjoy the benefits of Acceptance Sampling. The desired quality is, of course, called the Acceptable Quality Level or AQL for a given part.

(Figure #4 - Ford Sampling Tables)

The three 8½ inch by 11 inch tables (Figure #4) represent the Ford Acceptance Sampling Plan. After some months of experiment and experience with a variety of plans, we adopted one which was published a couple of years ago by the Armed Services as Joint Army Navy Standard-105. This is a book of sampling tables and characteristic curves about one-half an inch thick. It was of course necessary that we reduce it to a more usable form for our inspectors, including only those portions of the manual which described the single and double sampling techniques which we wanted to employ.

Briefly stated, under single sampling the inspector either accepts or rejects the shipment depending on the number of defective parts found in the random sample. Both the sample size and a limiting value for number of allowable defectives are found in the table. These are varied depending only on two factors, (1) the size of the shipment, and (2) the Acceptable Quality Level or AQL which the consumer has elected to use. Double sampling is the same idea carried to two stages for the sake of inspection time economy.

(Figure #5 - Receiving Inspection Close-up)

This is a typical receiving job. You will observe that the inspector's instruction sheets, blueprints, and sampling tables are there before him.

(Figure #6 - Receiving Inspection Area)

This figure shows a receiving area. Note that the sampling tables have been framed, for convenience, on the wall at each bench.

Now a word about increased inspection efficiency under an orderly program for Quality Control at receiving. The following observations concern the experience of the largest production parts receiving center in the Company; and I should preface the figures which shall be quoted by repeating what the quality control supervisor told us. He said that his gains resulted:

First: From the complete cooperation of people responsible for routing incoming materials through the receiving areas to stores.

Second: From the adoption of the Standardized Acceptance Sampling Plan.

and Third: From the training of inspectors in the use and understanding of the Acceptance Sampling tables.

And here is what happened. In the month of June 1949 they received 8½ thousand shipments, and a full year later, in August 1950, they received over 11 thousand shipments. Comparing these two months, the shipment coverage of the average inspector actually became five times as great in August as it had been in June of the previous year. In other words, where one shipment had been inspected and judgement passed in June 1949, five were being judged in August 1950, even though total receivals were only up about 29%. This was accomplished with no increase in inspection manpower, floor space, or equipment.

Before leaving the subject of receiving inspection I want to mention the planned use of the great body of quality information accumulated under an orderly Acceptance Sampling plan.

(Figure #7 - Trend Chart on Receiving Part)

Not only are we able to judge individual shipments, but we are able also to put inspection results to work in the form of quality trend charts. The kind of chart shown in Figure #7 has hundreds of counterparts all over the Ford Motor Company. Plotted at regular intervals, on a given part from a given supplier, each chart sums up from period to period the total percent of defectives found in all first samples drawn in the period.

Charts such as these are kept, mainly, on incoming quality problem parts. Copies are regularly furnished by operations quality control managers to those responsible in the Company for bringing about supplier improvement. Purchasing figures most importantly in this regard, and the comparative performance of each of several suppliers on a given part is an invaluable aid to the buyer in bringing the black sheep back into the fold.

(Figure #8 - Certification Agreement)

Another interesting offshoot of Acceptance Sampling is Quality Level Certification, in which we, for instance, as a consumer, modify our

stated right to reject and send back to a supplier each and every defective item in any shipment. The Quality Level Certification Agreement, shown here, is an attachment to the purchase contract wherein the vendor proposes to give continuous documented assurance that each of his shipments satisfies an Acceptable Quality Level which is mutually established as reasonable. We, the consumers, inspect according to the standard Ford Acceptance Sampling plan and absorb, at our cost, the incidental defectives in any shipment which is found acceptable to the established Acceptable Quality Level. And, of course, we return the shipments found rejectable. After the supplier gives adequate proof of his consistent ability to abide by the agreement, we are able to eliminate most of our inspection and only sample shipments infrequently in a Quality Audit.

The agreement is subject to cancellation if the supplier fails to achieve the consistent quality which he claims, or if for any other reason its continuance proves undesirable to either party. In the event of such cancellation we revert to the specific powers of rejection embodied in the original purchase contract.

The question always follows — "Why formalize this procedure when your Acceptance Sampling plan seems to do the same sort of thing without formality." The answer is found in three important areas. First, it is virtually impossible for any supplier to certify his shipments without using sound methods for process quality control. If he uses Statistical Quality Control effectively in his manufacturing processes, then both he and the consumer benefit in ways which should hardly require explanation. Second, it is necessary for the supplier and consumer to agree on an Acceptable Quality Level and to agree on the particular quality characteristics which are to be governed in the agreement. This may be the most important aspect of all — to be able finally to agree on what is or is not important to the consumer from the standpoint of quality. It follows automatically that the supplier can concentrate his quality control efforts on the particular characteristics of first importance to us. The third answer has to do with the psychology of a quality commitment. The urge of a supplier to stay with the agreement will be a strong factor in perpetuating the high quality we, at Ford, are most anxious to get from all of our suppliers.

We are only at the very beginning of a full-fledged Quality Level Certification program. After many months of experiment and testing we entered into the first such agreement with a supplier during August 1950. Others are ready to follow, but we are moving into this area with a caution born of its relative newness in industry.

With regard to the next link in the chain, that of Quality Control on sub-assemblies, I have here a few case studies which may be of interest. These jobs had proved incapable of correction under old-time inspection methods, even though the solutions, as time was later to prove, seemed quite simple. You have heard, before, that Quality Control is only an organized approach to the analysis of inspection results. These examples are certainly cases in point.

(Figure #9 - Assembly in balancing machine with control chart on machine)

The first case concerns the drive shaft and universal joint assembly.

To insure proper operation in the car as well as to eliminate vibration and noise, it is necessary to balance this assembly. Each completed assembly is taken from the conveyor and placed in the production balancing machine - shown in this figure - where it is revolved at 3200 revolutions per minute. The operator reads indicating dials which show the amount and angle of unbalance. He then welds counterweights to the tube of the shaft bringing the assembly into balance with a tolerance of ½ ounce-inches.

Before Chart Control was established, a process inspector would select random balanced assemblies several times daily and using one of the production balancing machines would test the assemblies. If he found any out-of-balance assemblies, he rejected all work produced since his last check, and all were of course returned to production for rework. This information was relayed to the job setter who then checked all of the balancing machines to make sure they were operating to the best of their capacities.

This situation resulted in a continuous controversy between inspection and production as well as complaints from our assembly plants. In addition, balancing machines were often arbitrarily shut down for repair since they were of course blamed for the defective assemblies.

To bring this operation into satisfactory control, we first placed Control Charts at each machine. On the machine in this figure the Control Chart is directly in front of the operator. The method of inspection was changed so that the inspector now systematically selects a sample of 5 completed assemblies from each of the seven machines, checks each for unbalance and records his readings for both the drive and axle ends on a worksheet. He then computes the <u>average</u> unbalance and the <u>range</u> of unbalance for the sample taken and plots them on the individual machine charts. If either the range or the average falls outside the control limits, the inspector puts the "Red (Out-of-Control) Hand" up. The operator or job setter then makes the necessary corrections to bring the job back into control. As long as the job remains in control, the operator gets the "Green (In-Control) Ball" which signifies that it is okay to proceed with production.

In addition all personnel were told how the inspector takes his samples, computes averages and ranges, and plots the control charts.

Preliminary data disclosed that both the average and the range portions of the charts were out-of-control. They were consistently running with more variation than the blueprint allowed. The averages were quickly brought into control by the operators once their errors were pointed out to them. They soon learned to work closer to zero than to the maximum allowable limit.

In studying the range, or variation from piece to piece, we found that it was more difficult to adjust to a satisfactory level. Further study of this operation showed several weaknesses in the process, and resulted in selling management on the need for heavier balancing machine cradles, recalibrating and magnifying the indicator dials and changing the sequence of a straightening operation from before assembly to after assembly.

Since these changes have been made we have been able to perform this operation at a satisfactory quality level as shown by the following charts.

(Figure #10 - Histogram - Drive end before and after - Drive Shaft and Universal)

The histograms shown in this figure give the before and after picture of Chart Control for the drive end of the assembly. The indicators on the balancer are calibrated in units of five hundredths ounce-inches and we have kept our charts in the same units - hence the maximum allowable out-of-balance of $\frac{1}{2}$ ounce-inches is equal to 10 units. Note that the percent defective on a sampling basis was reduced from 8% to zero %.

(Figure #11 - Histogram - Axle end of Drive Shaft)

This figure shows histograms of the other end of the assembly.

(Figure #12 - List of results - Drive Shaft and Universal)

The application of Chart Control on this operation resulted in the following improvements: First - Improved Quality Level. This operation is now actually running at zero percent defective insofar as random samples have revealed. The second item simply means that it has been many months since they had an assembly plant complaint. The next three items go hand in hand. The increase in production is the result of not having to do a lot of unnecessary rework and not having machines needlessly down for repair. In addition to these tangible results, worker morale has been greatly improved by the elimination of controversy and confusion.

The second case involves front wheel alignment — the adjustment of caster and camber angles on the front suspension linkage assembly. Every vehicle is, of course, final checked and, if necessary, adjusted before it leaves the final automobile assembly area. But the initial quality control should be and is exercised on the sub-assembly before it gets to the final line.

(Figure #13 - Setting Fixture - Front Suspension Linkage Assembly)

This figure shows the linkage assembly in place in the setting fixture. The Control Chart appears in the background.

Caster angle is adjusted by turning the lower bushing to the right or left until the pointer on the indicator reads within specified tolerance. The camber angle is set within indicated tolerance by turning the eccentric upper bushing, thus moving the upper end of the support inward or outward as the need might be.

Before Statistical Quality Control was applied, the inspector would spot-check individual assemblies on his gage, all of them having earlier been set by production operators. If he found any defectives, he would notify the production foreman who then had his men check their gages to the setting master. They would next re-check and re-set the defectives.

(Figure #14 - Caster and Camber Histograms - before and after)

This is a before and after picture of 100 sample pieces checked for caster and camber. In October 1949, shown in the upper half, 17% of the assemblies sampled were out of setting tolerance on left hand caster and 19% out of tolerance on left hand camber. Right hand settings showed a similar situation. The automobile assembly plants were giving this particular supplying plant a hard time, as you might guess, be-

cause incoming quality was so very poor. And their complaints were certainly justified. The effort of the supplying plant to remedy the situation is reflected in the distributions which appear in the lower half of the figure. Note that there are no tail ends out of tolerance. Corrections were not accomplished overnight; it took a lot of hard work and excellent cooperation on the part of all concerned.

The first step was to install Statistical Quality Control charts and gather the preliminary data from the operation. This preliminary data revealed that present equipment was not suitable for setting the assemblies to the limits required by blueprint specifications. This information was presented to Management, and they assigned Engineering the task of re-designing the setting fixtures.

At the same time, the production people attended several Quality Control sessions which presented to them the fundamentals of chart technique. This included Average and Range Control Limits, Dispersion, Out-of-Control conditions, Sigma Values, Chance Causes, the Normal Curve, and so on. As a result of increased understanding on the part of the production job setters, we soon noticed an appreciable tendency toward better control. This was caused by the operators working closer to the blueprint mean and at the same time decreasing their variability.

Experiments conducted by the quality control analyst also revealed that a great deal of variance existed between setting fixtures. A test was conducted by setting the inspection gage and the three production setting fixtures to zero-zero with the master linkage assembly. Next, several assemblies chosen at random were set zero-zero in the inspection gage and then inserted in each of the production setting fixtures. Theoretically, each assembly should have read zero-zero on each fixture. By actual test, however, the variance between setting fixtures was found to be as much as 26 minutes; this was a <u>very</u> unsatisfactory condition, as our total print limit is 30 minutes.

To correct the condition, every setting fixture was completely overhauled by the Tool Room, and all worn parts were replaced with new ones. This substantially reduced the gaging error. However, some error still existed, most of it due to the inherent flexibilities of the assemblies themselves. This fact was brought to the attention of production supervision, and it was suggested to them that they endeavor to set the assemblies to one-third of the blueprint specifications in order to compensate for the gaging error and the flexibility of the assemblies. They agreed to do this, and the Gage Department colored the faces on the dial indicators accordingly.

(Figure #15 - Dial Indicator Face)

A further improvement in quality level was immediately noted.

Our average percent of rejects kept dropping steadily over the months, and when we received our new, re-designed gages and setting fixtures, it dropped to zero. This assembly is no longer a Quality problem.

Summarizing, the following specific things were accomplished:

(Figure #16 - Improvements - Front Suspension Linkage Assembly)

First: Improved Quality Level.

Second: Final assembly plant complaints virtually eliminated.

Third: Increase in production due to elimination of confusion and reduction in number of assemblies requiring resetting.

Fourth: Improved worker morale.

The job is currently controlled by a five piece sample from each setting fixture every two hours, a nominal effort which proves completely adequate to all concerned. The red "Out-of-Control" hand and green "In-Control" ball are used, as in the previous case, to keep the shop posted on quality performance.

In closing, I want to make a few general remarks about the entire Quality program, whether it be in a small firm or a large one.

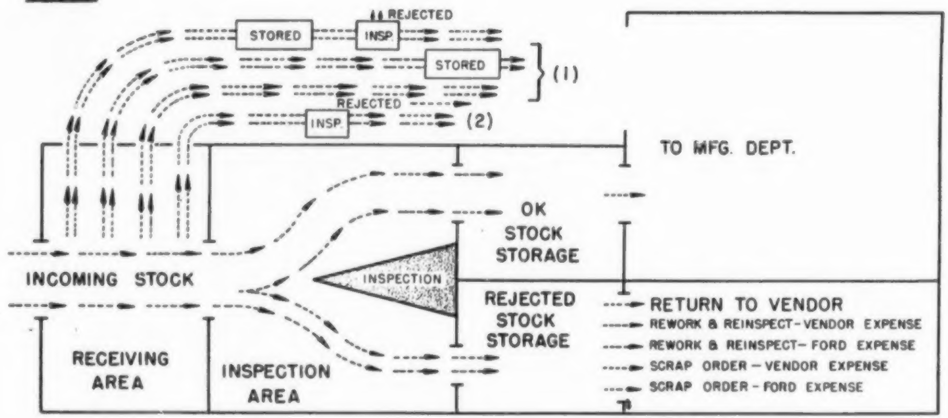
It is trite, but true, that the degree of quality attained depends largely on attitudes, and particularly those of the hourly workers. I am speaking specifically of the kind of quality which has to do with adherence to design. Industry is so very often guilty of saying something like this without making the least real and concrete effort to square up to the problem. We generally speak of the basic desire of people to do a good job, and then trust that a kindly providence will so govern the shop as to give this desire free opportunity for expression.

But in actual fact, it is up to Management to provide both the means and the stimulant for Quality Workmanship. The top organization must be staffed with men who demand quality, who are scrupulous in their decisions when quality is a factor, who are prepared to invest in quality equipment, and who put their faith in and support full use of sound Quality Control techniques. Management must practice the quality ideals it preaches, and I think this is a factor of prime importance in bringing about truly effective Quality Control.

We have been very fortunate in this regard at the Ford Motor Company. While our program is still a comparative fledgling, the successes we have enjoyed to this point result mainly from the aggressive stand taken by our top management in the area of Quality. Not only has Statistical Quality Control been firmly established as a basic Company-wide manufacturing policy, but the responsibility for Quality has been brought home repeatedly to every employee, whatever his position may be.

This is a must. None of the things I have discussed with you could be much more than attractive theories if we neglected the fact that Statistical Quality Control is just one means, and of course a vital one, to the end of building Quality into the product. It must be accompanied by a spirited attack of the problems it reveals, if its contribution is to be fully enjoyed, and the product is to emerge a better one for its application.

POOR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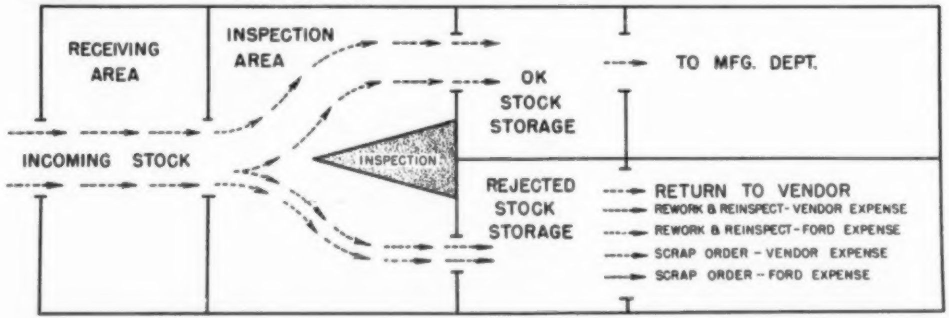
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RETURN TO VENDOR
REWORK & REINSPECT- VENDOR EXPENSE
REWORK & REINSPECT-FORD EXPENSE
SCRAP ORDER - VENDOR EXPENSE
SCRAP ORDER - FORD EXPENSE

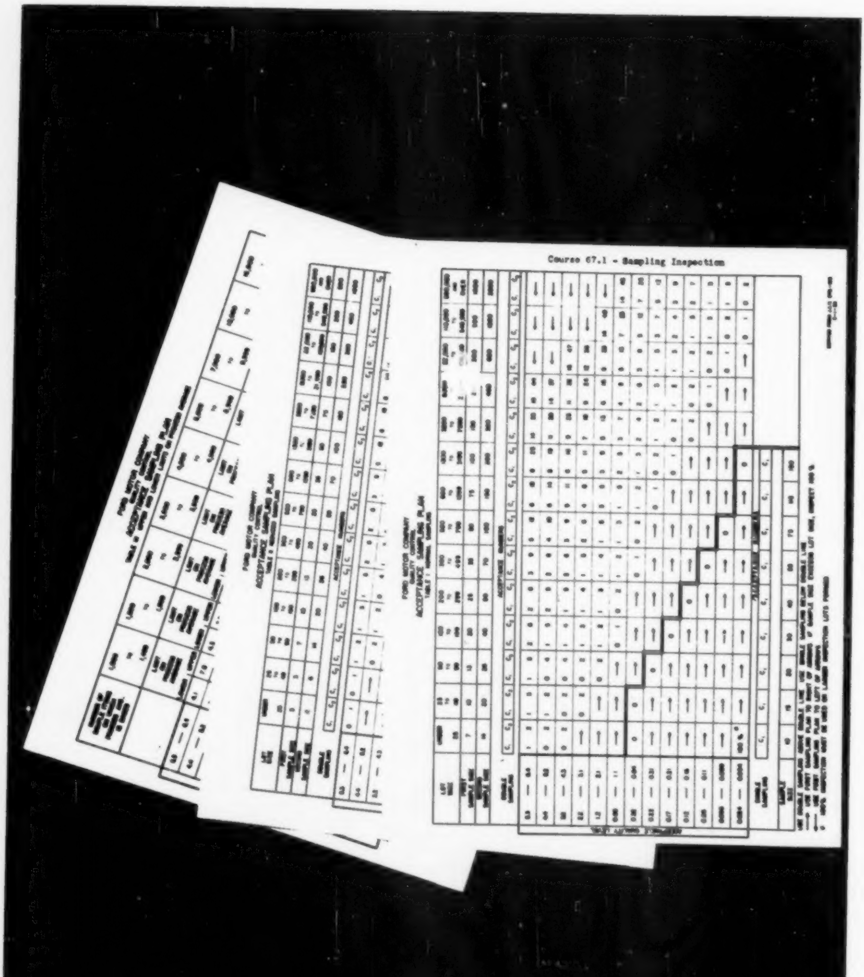

QUALITY CONTROL CHART
PUSH ROD ASSY.
HEIGHT - GRIND BEFORE
HEAT TREAT
SAMPLE SIZE-10
UCL
LCL

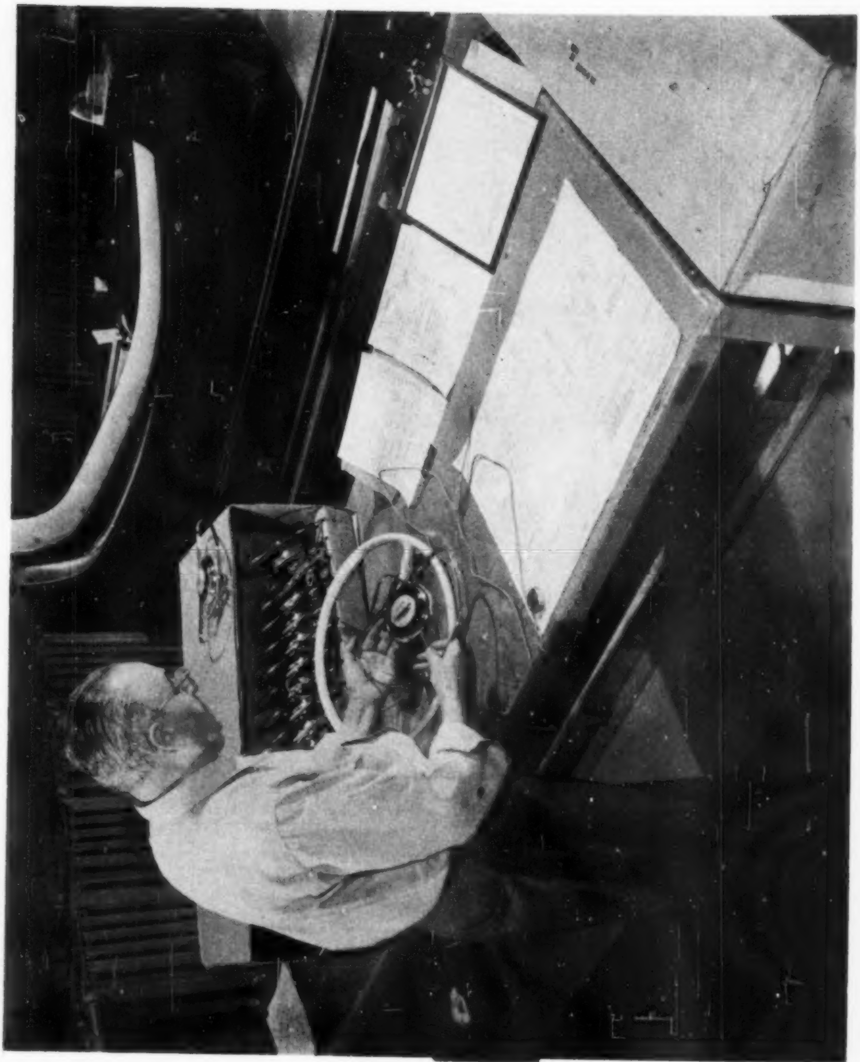
TEN PERCENT SAMPLING PLAN

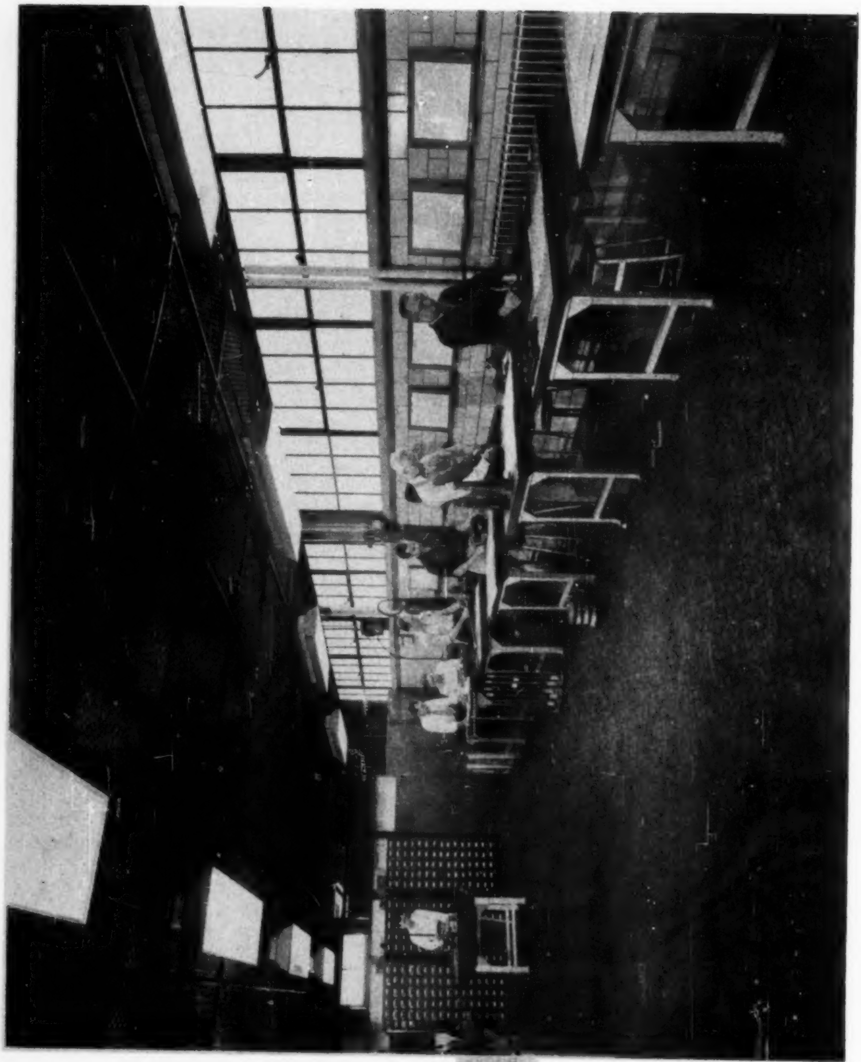
ON

5% DEFECTIVE SHIPMENTS

Lot Size	Sample Size	No. Accepted out of 100 lots	Ideal No. Rejected out of 100 lots
100	10 (10%)	60	100
200	20 (10%)	37	100
1000	100 (10%)	1	100


Course 67.1 - Sampling Inspection
FORD MOTOR COMPANY
ACCEPTANCE SAMPLING PLAN
FORD MOTOR COMPANY
ACCEPTANCE SAMPLING PLAN
FORD MOTOR COMPANY
ACCEPTANCE SAMPLING PLAN

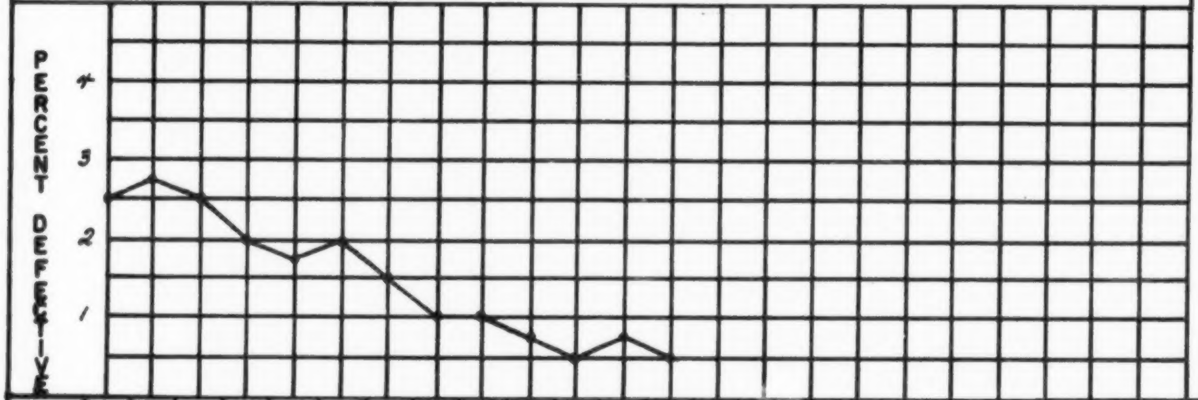




PART NAME LINER-MAIN BEARING	FORD MOTOR COMPANY QUALITY CONTROL DEPARTMENT QUALITY TREND CHART	PART NUMBER 1BA-123456
PLANT ENGINE		SUPPLIER JOHN DOE COMPANY

CHARACTERISTICS CHECKED

1. WIDTH
2. HEIGHT
3. WALL THICKNESS
4. SPREAD
5. WIDTH OF LOCKING LUG
6. VISUAL, OVER-ALL



QUAN. REC'D	10,240	12,131	12,175	11,180	12,050	[illegible]	12,010	10,130	10,200	11,200	10,30[illegible]	12,150	11,500
QUAN. INSP'D	800	550	[illegible]	750	[illegible]	[illegible]50	455	400	350	[illegible]25	575	[illegible]	550
PERIOD ENDED	5-15	5-31	[illegible]-15	[illegible]-30	7-15	7-31	[illegible]-15	8-31	[illegible]-15	9-30	11-15	11-30	11-15

PART NAME LINER- MAIN BEARING	SUPPLIER JOHN DOE COMPANY	PART NUMBER 1BA-123456

ATTACHMENT A

SAMPLE COPY
12-3-50

Form ___

QUALITY LEVEL CERTIFICATION AGREEMENT (OUTSIDE SUPPLIER)

SUPPLEMENTAL AGREEMENT made this ___ day of ________ 195__ between Ford Motor Company, a Delaware Corporation (hereinafter referred to as "Buyer"), and ________________ a ________ corporation (hereinafter referred to as "Seller").

Seller desires to enter into a Quality Level Certification Agreement with Buyer with respect to the parts supplied to Buyer under Buyer's Purchase Order No. ____ dated ____________, and Buyer is willing to enter into such an agreement. Accordingly, said purchase order is hereby supplemented and amended as follows:

1. For the purposes of this agreement, the critical, major and minor quality characteristics with respect to the parts to be supplied under said purchase order shall be defined as set forth in Exhibit "A" which is attached hereto. Acceptable Quality Levels for variations from the specified major and minor quality characteristics in any shipment shall be as set forth in Exhibit "A" hereof. (There shall be no specified Acceptable Quality Level for critical characteristics, inasmuch as they require complete adherence.)

2. Buyer shall, during the term of this agreement, accept such parts contained in any shipment delivered under said purchase order as may vary from the specified major and minor quality characteristics, but otherwise conform to the requirements of said purchase order, provided that neither of the foregoing specified Acceptable Quality Levels for major or minor quality characteristics is exceeded in respect to such shipment (as determined by Buyer in accordance with Buyer's Acceptance Sampling Plan, a copy of which is attached hereto), and further provided that there is no variation from specified critical quality characteristics. Neither this provision nor this agreement shall be construed to negate or limit any express warranty contained in said purchase order or any warranty that may be implied by law.

3. Seller shall supply, in connection with each shipment, such statistical or other data as may be requested by Buyer.

4. If either of the specified Acceptable Quality Levels is exceeded in respect to any shipment, as determined by Buyer as above provided, or if there is any variation from specified critical quality characteristics, Buyer may inspect such shipment and the next ___ shipments to the extent it deems necessary in order to determine whether Seller is able to supply shipments which satisfy the requirements of Exhibit "A". If Buyer determines upon the basis of such inspection that Seller is so able to supply, this agreement shall, unless terminated pursuant to Paragraph 6 hereof, continue in effect, provided that any such shipments as shall have failed to satisfy the requirements of Exhibit "A" may, at Buyer's option, be returned in its or their entirety for credit, or after notification to Seller, be returned in part for credit and any parts failing to meet said requirements which are retained by Buyer may be repaired at Seller's expense. If Buyer determines that Seller is not able to supply shipments which satisfy the requirements of Exhibit "A", Buyer may, by delivery of a written notice to Seller, terminate this agreement effective as of the date that any of the requirements of Exhibit "A" were first exceeded in respect to any shipment.

t from the requirements of said purchase order (other than major and minor characteristics) shall be subject to inor rejection in accordance with the provisions of the the said purchase order.

any other provision hereof, this certification agreement r party upon delivery of a written notice to the other

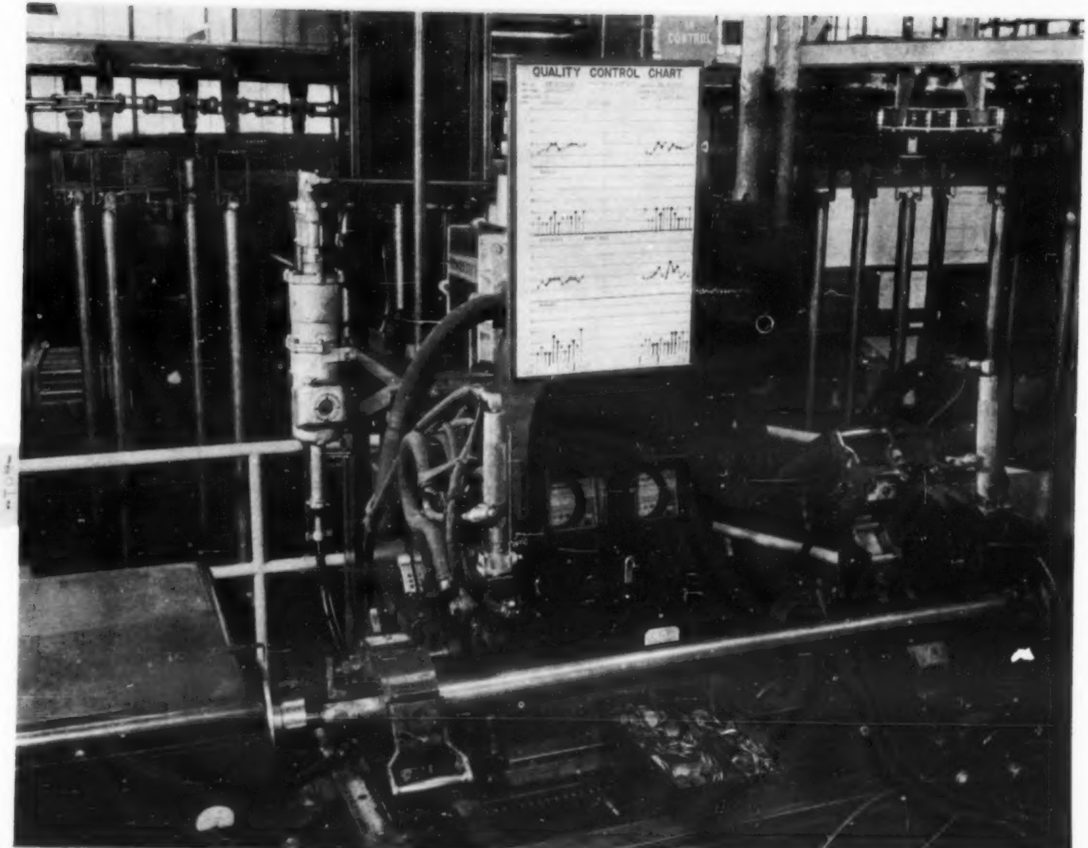
, have executed this agreement in duplicate as of the bove, to become effective as of ______________.

FORD MOTOR COMPANY

BY ______________

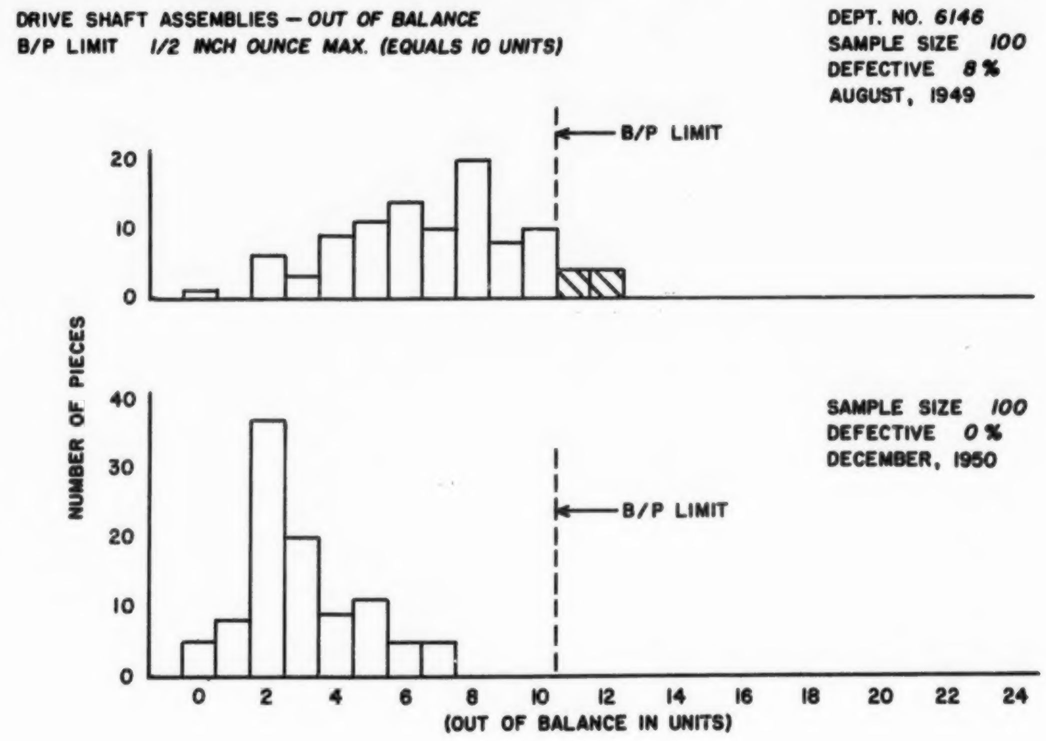
______________ CORPORATION

BY ______________


QUALITY CONTROL CHART
CONTROL

SHAFT & UNIVERSAL JOINT ASSEMBLY – DRIVE

DRIVE END

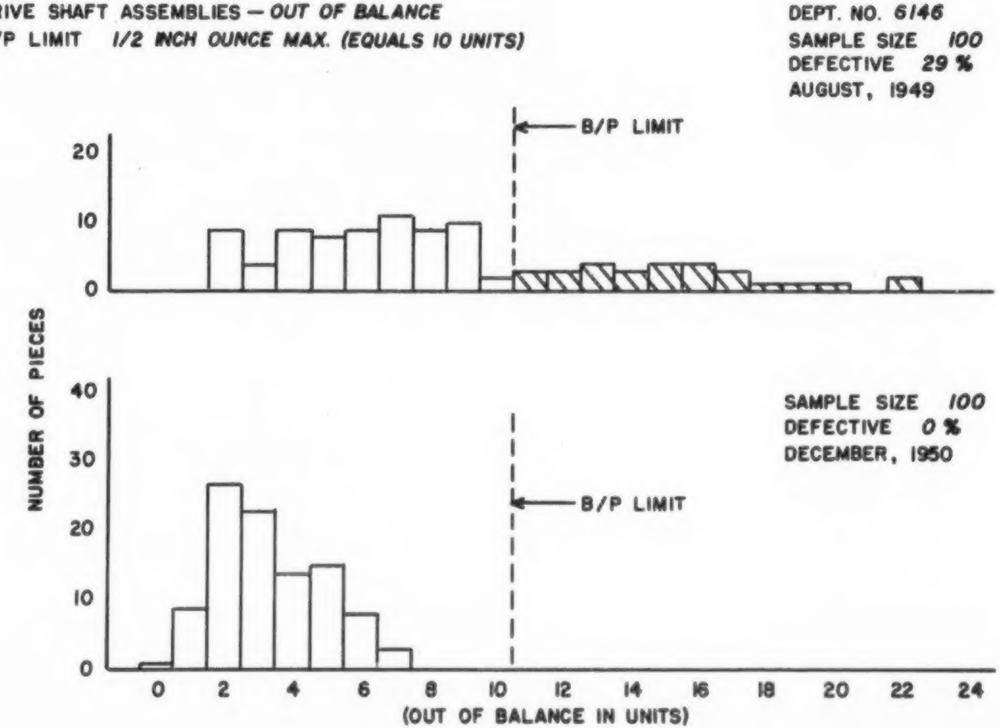


SHAFT & UNIVERSAL JOINT ASSEMBLY – DRIVE

AXLE END

DRIVE SHAFT ASSEMBLIES – *OUT OF BALANCE*

B/P LIMIT *1/2 INCH OUNCE MAX. (EQUALS 10 UNITS)*

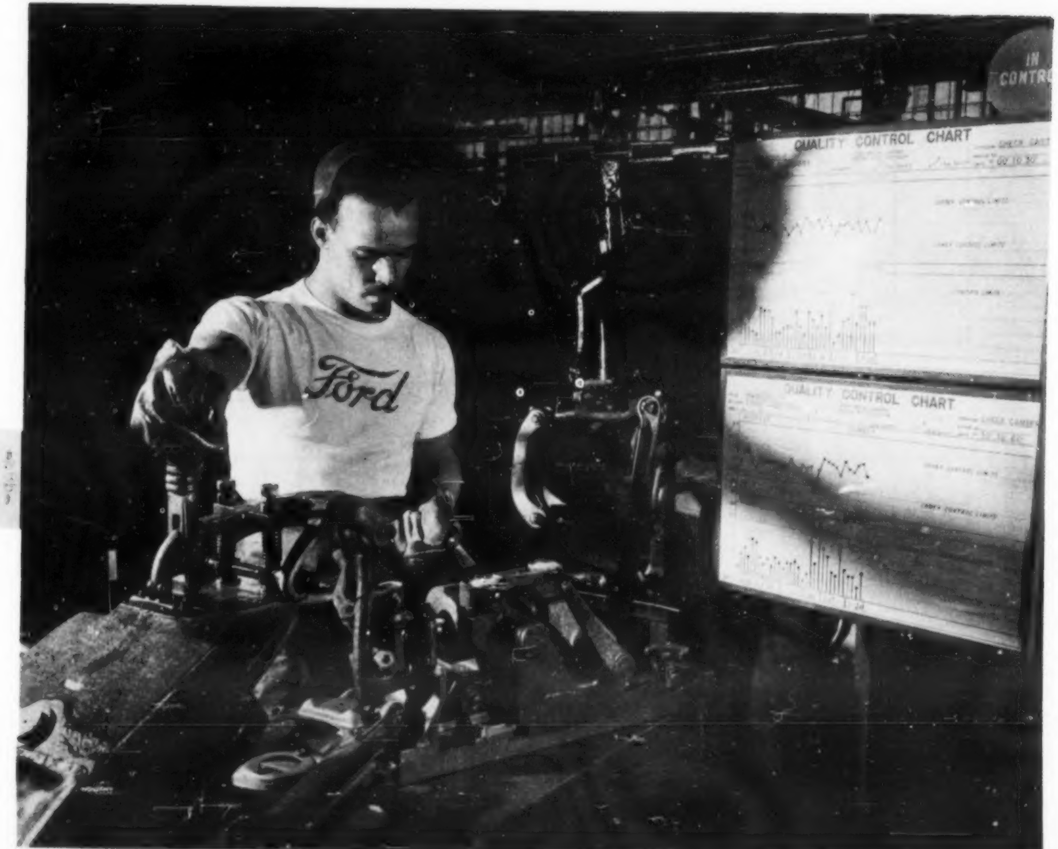


IMPROVEMENTS

DRIVE SHAFT AND UNIVERSAL JOINT ASSEMBLY

1. Improved Quality Level.
2. Decreased assembly plant complaints.
3. 46.5% increase in production.
4. Reduction in machine down-time for repair.
5. Rework reduced to a minimum.
6. Improved worker morale.

THESE IMPROVEMENTS ARE THE RESULT OF THE COOPERATIVE EFFORT OF PRODUCTION AND QUALITY CONTROL

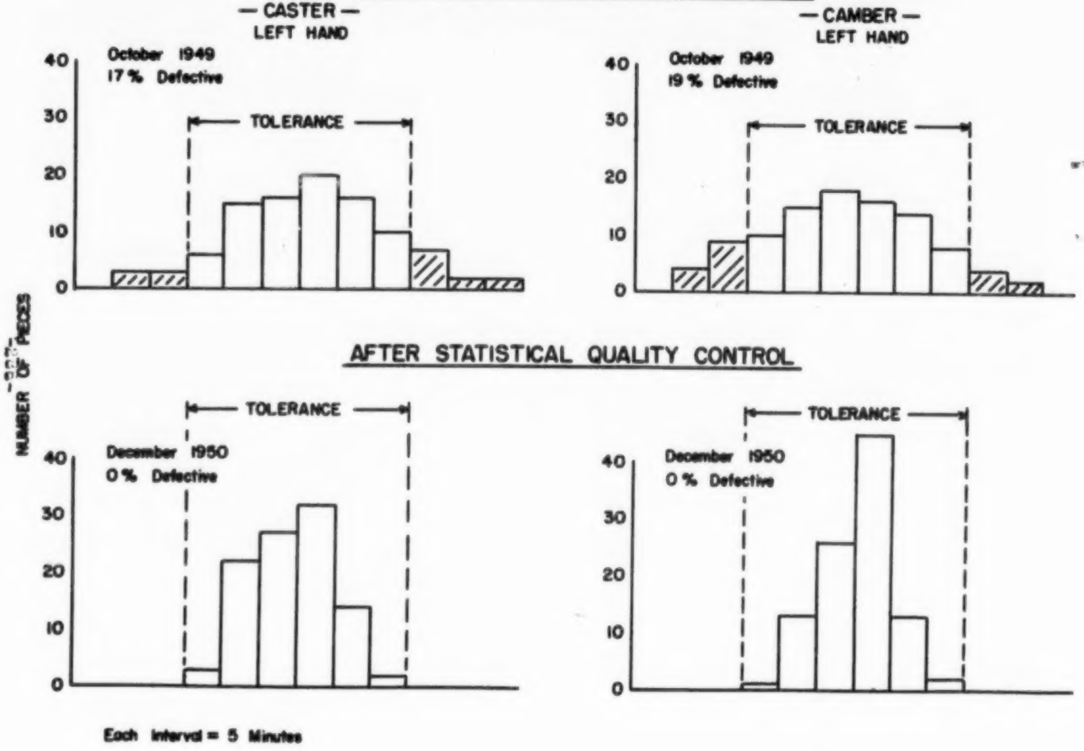

IN CONTRO
QUALITY CONTROL CHART
QUALITY CONTROL CHART
Ford

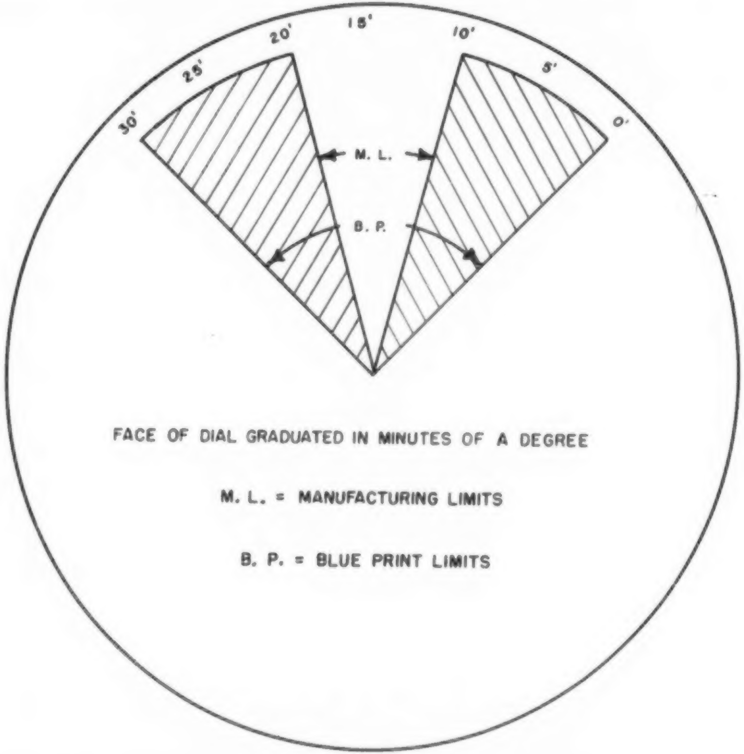
LEFT HAND CASTER & CAMBER SETTINGS

FREQUENCY DISTRIBUTION — 100 PIECE SAMPLES

BEFORE STATISTICAL QUALITY CONTROL

AFTER STATISTICAL QUALITY CONTROL





—ILLUSTRATION—
DIAL INDICATOR FACE
CASTER & CAMBER SETTING FIXTURE

IMPROVEMENTS

FRONT SUSPENSION LINKAGE ASSEMBLY

1. Improved Quality Level.
2. Final assembly plant complaints virtually eliminated.
3. Increase in production due to elimination of confusion and reduction in number of assemblies requiring resetting.
4. Improved worker morale.

THESE IMPROVEMENTS ARE THE RESULT OF THE COOPERATIVE EFFORT OF PRODUCTION AND QUALITY CONTROL

QUALITY CONTROL IN THE ASSEMBLY OF THE JEEP

Nelson G. Meagley
Willys-Overland Motors, Inc.

We at Willys-Overland have been adopting Statistical Quality Control methods to the different phases of our manufacturing operations and have been urging the increased use of these techniques by our vendors. Within our own processing, Quality Control methods extend from the forge shop, the foundry and the press shop at one end; through the machine shop, body shop, paint shop and trim shop in the center; and culminate in the assembly lines for the finished Jeeps. The program in some of the shops is still of an exploratory nature although in each case, a start has been made and we are expanding the work as rapidly as possible.

The first consideration in all phases of this program is to use inspection information to control quality. Production is told their quality level as rapidly and as accurately as possible, and in a form so as to separate the un-important quality level changes, where action is not necessary, from the important changes that require immediate attention.

Conventional X Bar R Charts, P Bar Charts or C Bar Charts are usually ideal for telling this information and these devices have had wide applications in machine shops and processes of many types. The control of quality on assembly lines, however, has not responded properly to these conventional techniques and we have found it necessary to alter some of the basic treatment of charts used in many of the assembly line problems.

THE PROBLEMS OF THE CONTROL OF QUALITY ON ASSEMBLY LINES

The statistical approach to the problem of the control of quality on assembly lines has not yet been adequately treated in literature. We have a unique set of conditions and we cannot group it with any other class of manufacturing. Assembly lines are characterized by a high labor force compared to equipment. Mechanization is confined almost entirely to material handling rather than material processing. Hundreds of people work in a confined area assembling the component parts into a vehicle passing by on a conveyor. Each person performs a series of assembly operations. The failure of any person to properly execute each one of his operations will usually result in a defect on the automobile.

Into this line is being fed a constant stream of hundred of thousands of parts daily. All of the manufactured or purchased material eventually winds up here. Many of these are complicated mechanical devices or elaborate arrays of stampings. All of them are expected to assemble without special treatment. Holes must be properly located. Shapes must not create interference. Threads must be of the proper pitch and free from burrs. Mechanical devices must operate properly, often the first time, without unusual attention for assembly.

Obviously, quality problems occur on assembly lines. Actually, there is always quite a number of problems occurring at any one time and a program for attending to them must be established. Corrective action must be based upon the specific problem and it cannot be grouped with other problems to determine control limits. For example, "tail lights don't

work" cannot be grouped with all electrical defects as a basis for action.

When percentage charts are made of the defective cars resulting from the types of defects observed on assembly lines, the process is usually not of the statistical controlled type. Almost all of these errors, separately, can and do run at zero for extended periods, so that the use of control limits leads to complications. More than one defect becomes an assignable cause.

OPERATING THE PROGRAM

Defects in many classes of industrial operations can be reduced to a few types with a considerable number of defects in each type. Control limits for groups can then be established for corrective action when previously established normals are exceeded by given probability values. Contrasted with this, assembly lines have a large number of types of defects with a small number of defects in each type. Control limits, when set statistically, will usually be less than one, showing there is an assignable cause for almost all the errors occurring. So many assignable causes exist that they lose their significance. At Willys-Overland, we have found that additional criteria must be established to separate the relatively un-important assembly line errors from the important quality changes that require immediate attention. The following methods are used:

Two classes of defects are recognized. The first, Class A, comprising the bulk of items, are the types discussed above where more than one a day is an assignable cause. The second, Class B, comprising all of the rest of the defects, are those showing a degree of statistical control — loose harness clips, for example. Assignable causes are determined in a conventional manner, using P Bar Charts with control limits.

THE TALLY SHEET AND THE QUALITY AUDIT

Throughout assembly, the Jeep is inspected to bring to light chronic conditions as quickly as possible. A traveler is placed on the body of each vehicle as it begins its trip down the line. Inspectors at stations along the line examine the Jeep and mark repair instructions on this traveler. A tally sheet, (Example shown in Fig. 1), is also kept and each time an item is listed on a traveler, it is also marked on this tally sheet. A running record is thus made of the defects occurring in assembly. To stop these defects as soon as possible, we must relay the information on these tally sheets to the people responsible for correcting the errors. Once each hour, a quality control inspector visits each inspection station and transfers the record of the defects found in the previous hour onto a Quality Audit Sheet (shown in Fig. 2). When the same Class A defect is observed twice in any one hour or three times in one day, it is listed as chronic and an immediate sequence of action is begun to attack the problem.

First, the quality control inspector charges the department responsible so as to know who to tell of the condition. A bolt missing, for example, can be the failure to insert the bolt by the assembly man. The body shop may be responsible for the mismatch of stampings so that the bolt cannot be inserted. A defective thread on a tapping plate may place it as a purchased item. The correct designation of the cause of

the error is, however, sometimes difficult when the defect first begins. Several keys to the problem are available without extensive trouble shooting. The inspector may contribut valuable information. Usually, the methods used to fix it will aid in the estimate. It is not unmusual for the cause of the defect to be undetermined after this superficial investigation and a more complete study may be necessary. The form used to record this study is shown in Fig. 6. In any event, all chronic defects must be charged someplace in the organization.

CHRONIC DEFECT CHARTS

Large Chronic Defect Charts, 5 Ft. x 4 Ft., are placed at key spots along the Assembly Line (See Fig. 3). The charts are covered with transparant plastic so that the surface may be written on with a wax pencil. As soon as a Class A defect is listed as chronic and is charged to the assembly line, it is posted on the particular chronic defect chart covering the location responsible.

The percentage of Jeeps having this defect is then posted each hour for the rest of the day even though this amounts to zero. The production foremen are responsible for looking at their board once each hour and knowing what is listed. If they feel that they are being charged for a condition they cannot control due to defective purchased items or work being fed in from other departments, then it is their responsibility to complain about this improper charge. This give a quick check on the accuracy of the charge and permits the correct department to be informed of their errors.

P CHARTS ON THE ASSEMBLY LINES AND IN FEEDING DEPARTMENTS

Class B defects are not placed on the chronic defect boards. Conventional P Charts showing P Bar as the previously established normal and 3-sigma control limits for determining assignable causes, are placed on the line close to the location where the work is performed. (See Fig. 4). A daily posting is then made showing the percentage of Jeeps having this defect. When the value exceeds the upper control limit, an assignable cause slip is given the production foreman requesting that he investigate and reports the changes in the assembly operation which was responsible.

Defects charged to feeding departments such as paint shop, body shop or machine shop are posted on Chronic Defect Charts or P Charts located in those departments. This is on a daily basis rather than hourly since a considerable float is usually provided between the departments and hourly checks are superfluous. The quality control inspectors in these feeding departments add the critical items onto their inspection list when this is practical. Tallys are then kept of the occurrence of the defect at the spot where it is being generated.

THE MASTER ALARM

Each posting of the occurrence of a chronic defect is considered an alarm. From previous experience, we have established a normal number of alarms which will be ringing in any given department at any one time. When the number exceeds this value by a significant difference, then a master alarm is sounded. This indicates that either a dangerous quality epidemic has broken out in that department or that the follow-up system

for investigating and correcting assignable causes is itself out of control. The main emphasis for policing the quality control system is then centered in this area. An investigation is made into the changes in the administration of the program which was responsible. C Type Charts, similar to Fig. 5, are used to obtain this information. The total number of defects charged to each department is plotted on charts showing C Bar (the previously established normal) and control limits. This is similar to the conventional type quality chart taking a day's production as a unit. On Willys-Overland assembly lines, we use this to control the control program rather than quality directly.

DAILY REPORT

A daily report on assembly line quality is issued to top and middle management by noon of the day following. The report lists (1) chronic defects which have been on the boards five times or more in the past ten days; (2) who is being charged for correcting the defect; (3) the number of Jeeps having the defect yesterday; and (4) where the defect was found.

This one quality control report has replaced five inspection reports formerly issued. The five old reports presented a mass of raw data giving the statistics of yersterday's inspection. Use of the data was cumbersome as it was difficult to separate the important from the unimportant and to judge the expected normal for the operations. The quality control report lists only those items which are important enough to require attention and the vital information about the defect is concisely stated for maximum information. Special assignment men from the Works Manager's office investigate the extraordinary problems that have prevented the shop from correcting the cause and cleaning up the defect.

The correction of the cause of the defect cannot always be made by production. Sometimes a change is required in the design of the product, tooling or material handling or additional inspection controls. A quality committee composed of representatives from the Product Engineers, Plant Engineers, Master Mechanic's office, Works Manager's office and Inspection meet at intervals to dêtermine the change required.

CONCLUSION

The use of quality control in the assembly of the Jeep follows the same basic thinking used for quality control in all phases of our manufacturing. First, we determine the limits within which control is possible or desirable; second, we examine the work and determine if it is beyond these limits; third, we inform all people responsible for quality when the limits have been exceeded - usually, by posting this information on charts, so that they can control their quality. We do this as quickly and as accurately as we know how using statistical methods to the fullest extent possible.

Assembly lines have peculiarities which require altering some of the conventional quality control approach. Most of the types of defects are not in statistical control so that more than one per day becomes an assignable cause. Hundreds of these assignable causes occur daily. A criteria for action less severe than a three sigma control chart is needed so as to point out the important assignable causes from the less important. Chronic defect charts are used for this purpose. A system has been developed at Willys-Overland to apply this thinking into our

assembly methods.

We have borrowed heavily from other manufacturers for ideas in quality control and many of the devices we use are not original with us. We are especially indebted to the Ford Motor Company, the Ford Motor Company of Canada and International Harvester Truck Plant in Fort Wayne, Indiana.

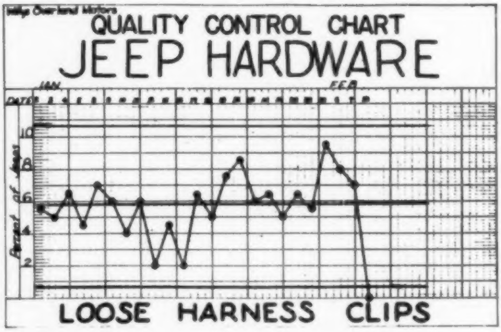


Fig. 4. P Chart used at Assembly station on Hardware Line.

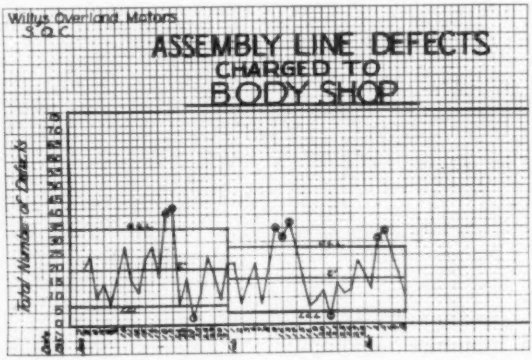


Fig. 5. C Chart showing total defects charged daily to Body Shop.

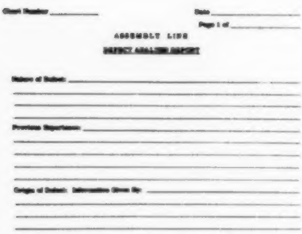


Fig. 6. Defect Analysis Report.

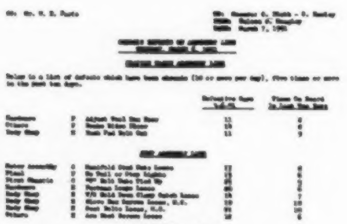


Fig. 7. Daily report showing Chronic defects on Assembly Line the previous day.

Fig. 1. The tally sheet used by Inspector at Final Assembly Line.

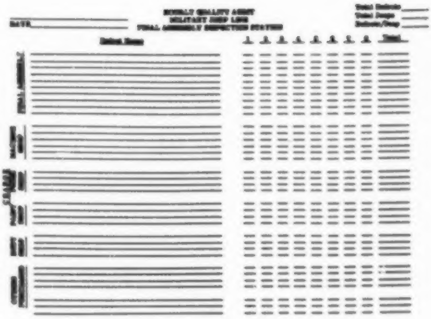


Fig. 2. Audit Sheet used by Quality Control Inspector.

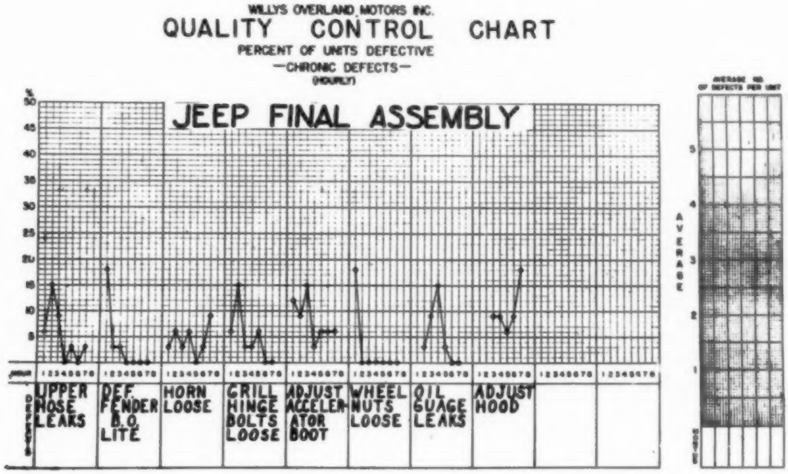


Fig. 3. Example of Chronic Defect charts placed along Assembly Line.

PAPERS NOT AVAILABLE AT TIME OF PUBLICATION

"Acceptance Inspection of Purchased Materials" by E. G. D. Paterson, Systems Quality Engineer, Bell Telephone Laboratories, Inc., New York, New York, and J. E. Palmer, Superintendent, Supplies Inspection, Western Electric Company, Inc., New York, New York.

"Practical Considerations in the Application of Statistical Techniques in Steel Processing" by John V. Sturtevant, Development Metallurgist, Irvin Works, U. S. Steel Corporation, Pittsburgh, Penna.

"The Puzzle in Vendor-Consumer Relationships" by Robert J. Miller, Supervisor of Electronics Quality Control, Erie Resistor Corporation, Erie, Penna.

"Consumer-Vendor Problems in Converting to Military Production" by Paul Fritschel, Manager of Technical Service, Commercial Equipment Division, Electronics Department, General Electric Company, Syracuse, N. Y.

"Vendor Quality is a Consumer Responsibility" by Leo J. Jacobson, Manager Quality Control Department, International Resistance Company, Philadelphia, Penna.

"Standards vs. Performance of Suppliers" by Alfred J. Winterhalter, Jr., Assistant Manager of Quality Control, Colonial Radio Corporation, Buffalo, New York.

"Gauging to Find the Facts" by Francis B. Murphy, Assistant to the Chief Inspector, Hamilton Standard Division, United Aircraft Corporation, East Hartford, Connecticut.

"Essential Design Qualifications and Correct Application of Gauging Devices Necessary for Effective Quality Control of Screw Threads" by Clinton V. Johnson, Partner, Johnson Gage Company, Bloomfield, Connecticut.

"The Application of Air, Electronic and Automatic Gauges to Control Quality" by W. Fay Aller, Director of Research, The Sheffield Corporation, Dayton, Ohio.

"Quality Control in Tire Manufacturing" by
John K. MacKeigan, Chief Inspector, Dunlop Tire and Rubber Company, Ltd., Toronto, Canada.

"The Quality Evaluation Policy of the Air Material Command" by Brig. Gen. Walter G. Bain, USAF, Quality Control Division, Wright-Patterson Air Force Base, Dayton, Ohio.

"Using the Normal Curve in Presenting Information to Suppliers and Design Engineers" by Louis K. Vollenweider, Assistant Chief Inspector, John Deere Waterloo Tractor Works, Waterloo, Iowa.

"Quick and Dirty Methods in Statistics - Part I" by W. Allen Wallis, Professor of Statistics, The University of Chicago, Chicago, Illinois.

"The Use of Statistical Techniques for Investigational Purposes" by Carl V. Garrett, Assistant Chief Inspector Allison Division, General Motors Corporation, Indianapolis, Indiana.

"Mechanical Aids for Presenting the Quality Control Story" by Robert Wagenhals, Director of Quality Control, The Timken Roller Bearing Company, Canton, Ohio. assisted by Lewis D. Rice, Quality Control Engineer, The Timken Roller Bearing Company, Canton, Ohio.

"A Shop Demonstration of Quality Control Principle and Practice" by Wendell H. Abbott, Supervisor, Statistical Section, Lamp Department, General Electric Company, Nela Park, Cleveland, Ohio.

"Military Standard 105-A" - A Standard Inspection System" byCommander B. L. Lubelsky, U.S.N., Assistant Director of Quality Control Division, Bureau of Ordnance, Department of the Navy, and William R. Pabst, Jr., Assistant for Statistics, Quality Control Division, Bureau of Ordnance, Department of the Navy.

"Statistical Quality Control's Role in Making Better Medicines at Eli Lilly and Company" by Ralph Ernsberger, Chief, Statistical Inspection Department, Eli Lilly and Company, Indianapolis, Indiana.

FIFTH NATIONAL CONVENTION

MAY 23 - 24, 1951

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APPENDIX

The following papers were all received after the publication deadline. For this reason they are not included in the index in the front.

Through special arrangement with the printer it has been possible to add these papers here.

ACCEPTANCE INSPECTION OF PURCHASED MATERIAL

J. E. Palmer
Western Electric Company, Inc.

E.G.D. Paterson
Bell Telephone Laboratories, Inc.

It is the purpose of this paper to describe some of the principles and procedures employed in the inspection of purchased material in the form of components or finished products. The authors' experience has been largely with procedures used in the Bell System, and the illustrations have therefore been drawn from this source. It is felt, however, that considerations leading to the choice of specific inspection techniques will be generally applicable even though the number and volume of items purchased and the number of suppliers involved may in some cases differ widely. In this presentation, stress has been placed on a discussion of the broader gauge factors underlying the engineering planning of inspection procedures rather than on specific sampling and control techniques which have been and are being so well covered in other material presented before the Society.

The most general form of acceptance inspection of purchased material involves examinations by the purchaser of individual incoming shipments of product. The type and extent of the specific inspection procedures employed depend upon such factors as the nature of the product itself, the quantities involved, the degree of quality control desired and the supplier's past performance with respect to quality. In practice, inspections of incoming product may vary from a superficial visual examination of a very small sample to the application of scientifically prepared plans based upon the latest quality control techniques. The tendency in recent years has been to reduce incoming acceptance inspection on the part of the purchaser by transferring to the supplier the responsibility for providing to the purchaser certified factual quality information of specified character and quantity.

This latter arrangement has been in effect for many years in the Bell System insofar as it applies to products manufactured by the Western Electric Company (the manufacturing unit of the System) for the Operating Telephone Companies. Bell Telephone Laboratories acts as the Quality Assurance agent for the Operating Companies in specifying the type and quantity of inspection results information to be furnished to the Laboratories as necessary for its continuous product quality surveillance. Thus the acceptance inspections covering specialized telephone apparatus and equipment such as cable, central office equipment, telephone instruments and the like - aggregating under the present System expansion program some several hundred million dollars worth of products annually - are all made by the manufacturer under arrangements which properly safeguard the purchasing telephone companies. Since it is possible to combine into one operation the inspections which the manufacturer as a prudent supplier necessarily makes on his own behalf with those required for assurance purposes by the customer, the inspection economies possible under this arrangement are very substantial.

There are many finished products needed for maintenance and for

additions to telephone plant, which are of a type commonly used in other industries and which may be purchased from numerous suppliers economically and at satisfactory levels of quality. These are known in the Bell System as telephone supplies and include such items as automotive equipment, motor generators, tools, first aid supplies, storage batteries, crossarms, and clay conduit. Western Electric Company acts as the purchasing agent for the Operating Companies in the procurement of such products. Total Bell System purchases of this class of material aggregated some $170,000,000 during 1950. Originally, it was the practice for each of the Operating Companies to insure by its own inspection that the quality of these products was satisfactory. The many advantages of a centralized inspection agency for this purpose soon became apparent, with the result that for many years Western Electric has acted not only as the purchasing agent for the System but also as the inspection agency in respect to these purchased products.

The purpose of any properly designed acceptance inspection plan is to assure at minimum overall cost a product whose quality is above minimum acceptable standards. Overall cost includes the effect upon the price of the product of the minimum standards established, the immediate and long-time tangible and intangible losses involved in the acceptance of substandard quality, and the direct costs of the application of the plan per se. Tolerances for defects, consumer's risks, and minimum sampling plans should always be determined with the overall cost factor as a background. The problem of establishing the best inspection procedure thus involves the determination of parameters of which some may be calculated with mathematical exactitude, some estimated, and some, in effect, just plain intelligently guessed-at. Who, for example, has ever seen a rigorous formula for the calculation of the effect of good will? Yet good will is important - especially so in a service industry. We must not lose sight of the fact that, excellent as they are, the techniques of sampling inspection and quality control are only tools to be wisely selected and guided by intelligent hands.

The Bell System includes a large number of Operating Companies and Long Lines areas throughout the United States. For each of these operating units Western Electric purchases materials ranging in variety from teletypewriter paper to linemen's rubber blankets, from small air valves to pole derricks, from aromatic spirits of ammonia to truck bodies, from cotton splicing sleeves to telephone poles.* Some of the items are available from only one or a few sources of supply. Some must be purchased from many sources in order to provide the quantities needed. Some are simple products commercially available at satisfactory quality levels with relatively few specification requirements. Some are specially designed by the System and covered by detailed specifications involving complicated testing equipment for their verification. Some are bulky and heavy items where trans-

* Western also purchases for the Operating Companies commercial products in the nature of office and janitor supplies, such as inks, soaps, waxes and polishes. Quality control of these materials is by inspection in its central testing laboratory of samples from purchased lots. Inspection procedures relating to such products are not discussed in this paper.

portation represents an important cost component. Under these circumstances there are several decided advantages in having a single agency inspect these products at the source of supply:

1. The special skills required for proper product inspection involve the training of fewer people than would be the case if each operating area were to inspect its own incoming shipments.

2. In the case of new products or new suppliers, relatively little information may be available upon which to formulate proper inspection procedures. In such cases, a preliminary review by the inspector of the supplier's plant facilities, processes, personnel, and quality control methods affords extremely helpful information upon which to base suitable acceptance inspection plans. A central agency with trained inspectors strategically located facilitates these reviews. In some instances, they have disclosed the prospective supplier's inability to produce product at satisfactory levels of quality and, hence, his inability to justify the placing with him of a purchase contract for the product.

3. Uniformity of inspection methods and acceptance criteria, especially in the case of "judgment" items, is more easily maintained - a feature necessary from the users' and fair from the suppliers' standpoints.

4. Shipping costs and, to a large extent, service delays arising from rejection of nonconforming material at destination are eliminated by rejection at source.

5. For any given value of protection (in respect to both producer's and consumer's risks) a smaller sampling ratio is required for the larger size lots inspected at the source as compared with the smaller size lots which would be inspected at destination.

6. Irregularities in product are earlier detected and corrected.

7. Optimum flexibility and efficient use of inspection manpower is facilitated.

A recent study made by Western Electric of raw materials and parts purchased for further manufacturing into completed items is of interest. The study covered a two months period during which 6,847 separate lots were shipped from 514 suppliers into one of Western's plants. Incoming or so-called receiving inspection was made by Western with the following results: 69% or 4,709 of the total lots received were nonconforming, and these were furnished by one third of the suppliers involved. All of the lots furnished by 22 suppliers were non-conforming.

For its centralized inspection of purchased materials at source of supply, Western Electric has as its Supplies Inspection Organization a group of some 170 people comprising over 120 inspectors together with the necessary staff and administrative personnel. The majority of the inspectors are located in areas close to the sources of supply. (Actually there are sixty basic locations throughout the country handling 1,000 suppliers.) Where volume and regularity of product

flow warrant, inspectors are resident full time at the suppliers' factories. Each man is trained in his particular inspection field. He is supplied with a group of instructions covering acceptance inspection procedures and acceptance criteria which apply to the products which he is called upon to inspect. As a matter of policy, established because of the many advantages of so doing, these instructions are prepared as separate documents from the design specifications although obviously they must be consonant with the latter. Copies of the instructions are also furnished to the suppliers as part of the supply contracts with Western, so that each supplier is familiar with what is expected in the way of inspection procedures.

All told, there are presently 600 such operating instructions covering standard products regularly required by the System. Like its counterpart in the inspection specifications covering products manufactured by Western, each of these instructions embodies the safeguards required by Western to fulfil its obligation as a Purchasing Agent for the Operating Companies as well as the information necessary for Bell Laboratories to fulfil its function as the Quality Assurance agent for the Operating Companies. Each instruction is tailor-made to fit a particular product, or group of similar products, and the circumstances under which this product is supplied. Underlying their preparation is the specialized knowledge of Bell Laboratories in sampling techniques as well as the information which accumulates from Laboratories' handling of all engineering complaints on products supplied to the Operating Companies. Underlying their preparation also is all of the practical experience which Western has had in its actual inspection operations. Throughout their life, the procedures are reviewed regularly for their completeness and correctness as part of the Quality Survey Program carried on by the System, in which a committee of Laboratories, Western, and Supplier representatives reviews all factors having a bearing on the quality of the product which is being supplied. Let us examine a few of these individual instructions and the reasons for the particular procedures and criteria incorporated in them.

Telephone Poles

For outside plant line construction purposes, the Bell System uses some 800,000 poles yearly. They vary as to species - Southern pine, Western larch, cedar, etc. - as to diametrical size, as to length, and as to the preservative treatment applied to insure a satisfactory life under the particular environment to which they will be subject. They are purchased from more than fifty suppliers located in timber areas throughout the country.

A telephone pole is essentially a product of nature. To be sure, it comes from a tree which man selects, cuts, trims, shaves, frames, and subjects to preservative processes. But in respect to its shape, its intrinsic strength, and the size, number, and location of its knots, it is a product of nature. As such it has been potentially subject to all of nature's vagaries: drouth, fire, attack by insects, disease, snow loads, wind damage, etc.

One of our best indications of past environmental variations in a locality is obtained from a study of the effects left upon the ring-growth of a tree which grew in the area. To us as quality engineers, each of these environmental factors is properly characterized as an assignable cause of variation with all its implications from the standpoint of quality control. Our inspection problem is made no easier by the knowledge that the pole will have reached us as a finished product only after it has gone through several selection processes - each none too well defined as to criteria, and each with its effect on the final shape of the quality distribution of the lot of which the pole is a member. Shipping expenses represent an important element in the cost of the pole. The cost of erecting the pole in place and of adding the equipment which it is to carry is many times the cost of the pole itself. Long useful life is hence economically vital. Potentially weak poles introduce hazards to line construction and maintenance personnel, to expensive line equipment, to continuity of telephone service, and, if the pole is installed in a busy area, to the general public. All of these factors point to a low tolerance for defectives and to a low consumer's risk. After a pole has been impregnated with preservative, many of the tell-tale evidences of weakening effects such as decay are obscured. We must therefore examine the pole before the preservation process - "in the white," as we say - and, in fact, we find that we must so examine each pole in each lot. While this is technically a 100% inspection, we realize, of course, that actually we see only the surface. Fortunately, by the skilled inspector much can be learned from a surface examination, and he can and will take increment borings or fresh butt or top cuts on those poles whose surfaces cause suspicion. But it is evident that the inspector must be highly trained to recognize those many characteristics which affect the timber quality. And it is evident that it is unlikely that the same individual will be equally well qualified to inspect motor-generator sets. In other words, he must be a specialist in timber product inspection. (The average total inspection time per pole is only three minutes.)

Preservative is introduced into the pole to protect it against insect damage and disease. Any niche in untreated wood left by a climbing iron spur or a surface check is a potential resting place for a spore of wood-destroying fungus. Any exposed untreated wood below groundline offers an avenue for attack by a colony of termites. To be effective, the preservative must contain sufficient amounts of toxic agents, it must be properly dispersed in the pole, and it must neither "bleed" (exude from the pole) nor leach out over a long period of years. Fulfillment of some of these requirements can be checked by inspection of the finished product and by analysis of the preservative.

For example, statistical analyses have been made of data obtained from test borings from thousands of treated poles representing the variations in the preservative process in respect to depth of penetration and percentage of sapwood penetrated. As a result of this study, it has been determined that in the case of the smaller sizes of poles treated (preserved) as a single charge in the treating cylinder, a single test boring from each of twenty representative poles in the charge will suffice as a sample. If eighteen or more

borings meet certain penetration limits, the entire charge is acceptable for this feature. If 16 or 17 borings meet requirements, each pole in the charge should be bored and its acceptability determined on the basis of its individual boring. If less than 16 borings meet requirements, the charge is not acceptable without retreatment.

Variation in treating results in the larger size poles, and evaluation of the sampling risks involved, necessitate that a boring be taken from each of the larger poles and that each such pole be accepted or rejected on the basis of the results of its individual boring. In respect to certain features of the preservative dispersion in the pole, and to freedom from the likelihood of bleeding, there are no economically applicable "end requirements" and resort must be had to specifying and checking the preservative process itself*.

To provide the inspectors with the information necessary for pole inspection, three general instructions have been prepared:

1. Preliminary Inspection of Poles
2. Treatment and Final Inspection of Timber Products
3. Inspection of Wood Preservatives

Supplementing the foregoing instructions, there are separate instructions to cover such detailed subjects as Decay in Timber, Checking of Gauges at Wood Preserving Plants, Moisture Tests on Wooden Materials, Percent of Sapwood Penetrated, Classification of Defects, etc. All told, some 28 instructions including 46 pages of text, tables, charts, and diagrams have been issued to insure that the techniques applied to the acceptance inspection of telephone poles are such as to provide product at or above the minimum specified level of quality.

* Specification of the design intent in terms of end requirements is always desirable where economically feasible, both from the standpoint of manufacture and inspection. Very recently Bell Laboratories has developed specifications which base acceptability of preservative treatment upon end requirements. Processing requirements are eliminated from these specifications except for prohibitions concerning certain detrimental practices which might otherwise be employed during the treating process. Little commercial experience has been had, however, under this new type of specification. The specifying of processing methods for preservative treatment is traditional and still the general practice in the procurement of treated timber products.

Hardware

There is a large group of metal details used in outside plant construction which falls in the category known as outside plant hardware. Included are such items as bolts, braces, brackets, clamps, metal castings, guards, rings and rods. Annual purchases of these items aggregate some 20,000 tons. While they differ substantially as to size and shape, they are similar from an inspection standpoint in that they are made of like material and have as their main requirements, strength, "assemblability" and durability. They are normally furnished regularly, and frequently in such quantities as to require a resident inspector at the plant. Many of them can be and are inspected under one general inspection instruction. Their principal specification requirements relate to material strength, freedom from brittleness, nut fit for threaded items, dimensional limits to insure strength and fit, and adequacy of the protective galvanizing coating.

Since these items are made of materials and by processes which should be susceptible to good control, it would appear that some of the straightforward statistical sampling techniques would find ready application. While they would indeed from a purely statistical standpoint, there are other circumstances which lead to the adoption of sampling plans which at first glance appear almost crude in terms of sampling theory. The following excerpt (Fig. 1) covering "Surface Inspection" from the general inspection instruction on outside plant hardware shows that not only does the sample size represent a percentage of the lot size (up to a maximum number), but the acceptance criterion is simply a limiting percentage of the sample itself. Obviously from a mathematical point of view the risk of acceptance varies with lot size and the table bears no ear-marks of a calculated minimum inspection plan.

		SURFACE INSPECTION	
Class of Hardware	Sample Size	Report as Conforming	Report as Non-Conforming
CLASS A: Pole balconies Pole seats Iron and Steel castings except cable dogs, grade clamps, strand connectors and saddle supports for cable Welded (except spot welded) articles Iron or Steel Pipe All other Hardware in lots of not over 100 articles	100% of the lot	All articles which conform	All articles which do not conform
CLASS B: Hardware having a thread and nut, for which a definite nut fit is specified, submitted in a lot of over 100 articles	5% of the lot but not less than 100 or more than 1000 articles	Entire lot if: (1)Articles not conforming for nut fit are not over 1%, and: (2)Articles not conforming for patent marking are not over 10%, and: (3)Articles not conforming for other features are not over 3%, and: (4)Defects are not pronounced.	Entire lot if: (1)Articles not conforming for nut fit are over 1%, or: (2)Articles not conforming for patent marking are over 10%, or: (3)Articles not conforming for other features are over 3%, or: (4)Defects are pronounced.
CLASS C: All Hardware not in CLASS A or CLASS B	3% of the lot but not less than 100 or more than 1000 articles	Entire lot if: (1)Articles not conforming for patent marking are not over 10%, and: (2)Articles not conforming for other features are not over 3%, and: (3)Defects are not pronounced.	Entire lot if: (1)Articles not conforming for patent marking are over 10%, or: (2)Articles not conforming for other features are over 3%, or: (3)Defects are pronounced.

Figure 1. Hardware - Plan for Surface Inspection

Before we criticize too severely the sampling plans illustrated, let us review some of the circumstances which led to their adoption and their continued use in the face of the availability of so many more statistically conventional plans, of which the Bell System itself has developed quite a few. Note in the first place that items whose use involves personal hazards, such as pole seats and balconies, or items which involve processes such as welding and casting in which flaws may be detected visually, are inspected 100% in any event. Note also that 100% inspection is applied to any lot not in excess of 100 units. This provision protects by 100% inspection many of the larger and more expensive items which are supplied in small lot sizes. Note further that with classes B and C hardware, three different percentages of defectives (1, 3 and 10), depending upon the seriousness of the defect involved, are permitted in the sample selected. While, as indicated above, the plans do not thus represent any fixed values of AOQL, they insure consumer protection against substandard lots of a higher order than would be provided by standard 1%, 3%, and 10% AOQL plans.

Most of the items are small and are submitted in large lot sizes in kegs, boxes, or similar containers. The percentage sample which is operative in these circumstances facilitates dispersion of the sample selection over the entire lot. The main attractiveness of the plan from the inspector's standpoint is its simplicity and the ease with which it may be memorized and applied from one inspection lot to the next without recourse to a series of sampling tables. Since it provides the Western Electric inspector with an economical procedure, all things considered, and since it satisfactorily restricts the consumer's risk and provides adequate information to Bell Laboratories, it properly fulfills the dual purpose which is common to all of the inspection procedures.

Special sampling arrangements are in effect, of course, to cover such items as strength, freedom from brittleness, and adequacy of galvanizing. Checks for these features often involve destructive testing. The sample sizes are tailored to recognize the importance of the characteristic in the intended use of the item and the past experience in respect to process averages. It is of interest in this connection to relate that some years ago an extended study was made of galvanizing process results. Specifications commonly require that each galvanized item withstand four one-minute so-called Preece test dips. This is designed to insure a minimum thickness of galvanizing at thin spots and thus the weather resistant properties of the coating. As a result of our studies, requirements were set up on the basis of $\bar{X}$ and range of dips for samples of four from each hardware lot. Subsequent data over a period of years disclosed that the galvanizing process was so well controlled as to permit on all but new items or new suppliers (which must first qualify) what amounts to a periodic verification of the galvanizing process. This consists in the inspection of a few specimens monthly on a straight attributes basis.

Although this single general instruction on the inspection of hardware suffices for some 450 items, there still remains a large number of hardware products which, because of the special nature

of their requirements or the circumstances under which they are purchased, require special individual treatment. In such cases a separate inspection instruction is prepared to cover them. Consider, for example, cable rings which are used to suspend lead covered aerial cable from the supporting steel messenger strand between individual poles. In addition to the usual requirements specified for hardware, it is especially important that the bearing surface of the rings be smooth so as to avoid ring cutting of the lead sheath during the movement which may occur between the rings and the cable. These rings are supplied intermittently in fairly large numbers at a time by two or three manufacturers. The significant feature of the individual instruction prepared for the inspection of these rings is illustrated in Fig. 2, which shows the sampling table for surface inspection. Note that it is an adjusted and compressed lot tolerance double sampling table including three acceptance criteria for the one sample selected to represent the lot. The criteria involve a 3% lot tolerance for "other defects," a 4% lot tolerance for projections over 1/64", both at a consumer's risk of 10%, and a large lot tolerance (about 20%) for "finger feel roughness" which represents a very severe test for roughness of a magnitude detectable by touch.

	Inspection Sample Sizes			Allowable Number of Defective Rings: Projections Over 1/64"		Finger Feel Roughness Including Projections Over 1/64"		Other Defects	
Lot Size	n_1	n_2	$n_1 + n_2$	c_1	c_2	c_1	c_2	c_1	c_2
10,000 or less	200	380	580	3	17	25	104	2	11
10,001 to 20,000	205	470	675	4	18	27	131	2	13
20,001 to 50,000	205	510	715	4	19	27	140	2	14
50,001 to 100,000	205	530	735	4	21	27	147	2	15
Over 100,000	260	540	800	5	23	47	157	3	16

Figure 2. Cable Rings - Sampling Plan for Surface Inspection

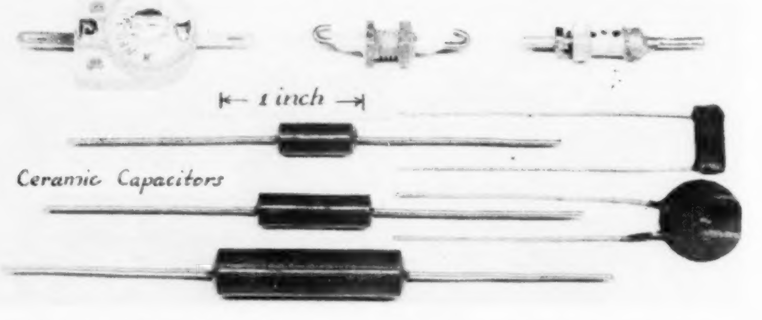
Similarly, an individual instruction covers a group of about fifty sizes and types of anchors used in guying, another covers manhole frames and covers, and so on,- each designed to fit the special features peculiar to the product covered.

Electrical Components

A rather specialized inspection problem is presented in the purchase of electrical components such as resistors, varistors and capacitors which are used in large numbers to build up networks and amplifiers. While most of these are shipped to Western Electric for manufacturing purposes rather than direct to telephone companies, the procedures followed in inspecting them are felt to be of sufficient interest to warrant their description. The use of these components contemplates operation over a long period of years with no appreciable change in their electrical characteristics. In the usual case, those features which insure the desired service life

for such components are presumed to be incorporated in the design, and inspection, where it is made at all for such purposes, is confined to type-testing one of the first units to be supplied. Experience has shown us, however, that, with current trends in design which contemplate exacting performance from units which have been greatly reduced in physical size, process variations from time to time may introduce life-performance limitations of serious magnitude. It is desirable, therefore, that some form of inspection procedure be formulated which will not only include the normal lot-by-lot acceptance inspection but will supplement it in such a manner as to afford continuing evidence as to the integrity of the manufacturing process from the standpoint of service life insurance.

In addition, therefore, to the normal mechanical and electrical requirements which may be verified immediately by straightforward testing procedures, accelerated aging requirements are specified in the design specifications to insure satisfactory quality from a life standpoint. Tests for these latter requirements are destructive, expensive, and time consuming. Until they are completed, however, the actual quality of the product is not verified. This means that life tests must be confined to a relatively small sample, and that indications of acceptability of the product must be obtained as early as possible in order to permit shipment of the lot in question.



The instruction covering the inspection of ceramic capacitors will serve as a good illustration of the manner in which an inspection problem of this kind is handled. A double sampling lot inspection table with a lot tolerance of 3% and a consumer's risk of 10% is provided to cover the sample to be inspected for dimensions and surface inspection (including such features as finish, end sealing, tightness of terminals, freedom from sharp edges, spacing and location of color code, etc.) A specified portion of the surface inspection sample is subjected to those electrical tests, such as dielectric strength, capacitance, and insulation resistance, which can be made at once. Figure 3 shows an excerpt, Section 4, of the instruction. (This section covers the inspection of the product for features which have significance from the standpoint of service life and which involve subjecting the capacitors to extreme temperatures and accelerated aging.) Par. 1.7 referred to at the heading of the section states that for this particular purpose production is arbitrarily divided into lots of 3500 or 7000 of one type of capacitor.

*4. INSPECTION: PERIODIC (Par. 1.7)

4.1 Table of Sample Sizes and Allowable Defect Numbers.

## Inspection Item	Normal Inspection # Lot Size	Sample Size-n	Allowable Defect Number-c	Reduced Inspection Lot Size	Sample Size-n	Allowable Defect Number
Life	3500	12	1	7000	12	1
Seal	3500	12	1	7000	12	1
Torque	3500	12	1	7000	12	1
Drip	3500	12	0	7000	12	0
Ins.Res. at Ab. Temp.	3500	12	0	7000	12	0
HiFreq. Imped.	3500	12	0	7000	12	0
Temp. Coeffic.	3500	6	0	7000	6	0
Cap. Drift	3500	6	0	7000	6	0
Vibration	3500	6	0	7000	6	0

#If during any quarter combined production under a single specification is less than 3500, samples for these tests shall be selected as shown under Normal Inspection considering that quarter's production to be the inspection lot.

##When pertinent.

4.11 In so far as practicable the number of pieces selected from each list number shall be in the same proportion as the amount of that list number in the lot, except that pieces selected for Torque Test shall be selected by size and type of threaded part rather than list number.

4.2 Sampling Procedure for Inspection per Paragraphs 4.41 to 4.44, inclusive.

4.21 Normal Inspection - Select representative sample n from lot for test for each inspection item as shown under Table, Paragraph 4.1.

4.211 Place respective samples on Life Test, and Seal (Cycling) test (when pertinent), and make other tests and determinations (See Par. 4.4).

4.212 If defects found in tests other than Life and Seal exceed allowable defect number, report lot as non-conforming.

4.213 At end of Seal and of 100 hours of Life Test check samples as noted in Paragraph 4.4; if no defects are noted for either inspection item, shipment of lot may be permitted pending completion of test (provided lot is not being held for disposition under Par. 4.212).

4.2131 If not more than one defect is found for Life Test hold lot until completion of full 250 hours of test.

4.2132 If more than one defect is found for Seal or for Life Tests at end of 100 hours, continue remainder of sample on test but class lot as non-conforming and forward test results to New York Office immediately.

4.214 If shipment has been authorized at end of 100 hours of test but allowable defect number c has been exceeded at end of test, notify New York Office immediately giving full details.

4.22 Reduced Inspection-When 4 consecutive conforming lots have been found for an inspection item under Normal Inspection, inspection for that item may be made in accordance with the Reduced Inspection Table.

4.221 Sample selection and criteria shall be applied for Reduced Inspection in the same manner as that enumerated under Paragraphs 4.21 to 4.214 inclusive.

4.222 If a lot is found non-conforming under Reduced Inspection, sampling and test shall immediately revert to the Normal Inspection basis.

4.3 Sampling Procedure for Inspection per Paragraph 4.45.

4.31 Select random sample of at least 10 specimens of each ceramic component used during current fiscal quarter from supplier's stock and inspect per Paragraph 4.45.

4.32 If any specimen does not conform, report current product involved as non-conforming.

4.4 Tests and Determinations.

4.41 Capacitors subjected to Torque, Accelerated Life and Seal (Cycling) Tests shall be checked for Dielectric Strength Capacitance, Insulation Resistance (and Q, when pertinent) before test, and Capacitance, Insulation Resistance (and Q, when pertinent) after test; Torque Test samples shall be checked for Dielectric Strength after test; also; the Capacitance, Insulation Resistance (and Q, when pertinent) values obtained before and after test shall be recorded.

*4.42 Temperature Coefficient, Capacitance Drift, Wax Drip, Torque, Insulation Resistance at Abnormal Temperature, High Frequency Impedance (Q), and Vibration (when pertinent) tests.

4.421 Each capacitor in the respective samples (Par. 4.21 or 4.22) shall be tested or inspected.

4.43 Accelerated Life Test.

4.431 Each capacitor in the sample shall be tested. The Capacitance and Insulation Resistance shall be measured and recorded at the end of 100 hours as well as before and after test. Capacitors subjected to this test shall not be shipped.

4.44 Seal Test (Cycling)

4.441 Each capacitor in the sample shall be tested.

4.45 Water Absorption

4.451 The sample (Par. 4.3) shall be tested for water absorption as outlined in Paragraphs 4.4511 to 4.4514, inclusive (which are based on Method A, A.S.T.M. D116).

4.4511 The specimens (Par. 4.31) shall furnish at least five test samples with a weight of 2 grams to 50 grams each when weighed on a chemical balance, and shall have at least 25% of the surface newly fractured (unless otherwise stipulated).

4.4512 The test samples shall be dried at 120°C. for two hours in an oven capable of maintaining a temperature of 120° ± 5°C., cooled in a desiccator to approximately room temperature and each test sample weighed immediately upon removal from the desiccator.

4.4513 The samples shall be totally submerged in briskly boiling distilled water for 30 minutes, removed and quenched in distilled water at room temperature (about 20°C.), the surface water wiped off with a soft cloth and the samples weighed immediately.

4.4514 The percentage water absorption of each test sample and the average percentage water absorption of all samples tested shall be computed from the dry weight and weight after immersion of each sample.

4.46 If a defective capacitor is found in sample when tested as noted in Paragraph 4.41, it shall be replaced by a conforming unit selected from the lot.

4.47 When time is available during the course of the inspection, the inspector shall observe the method of construction.

Figure 3. Ceramic Capacitors, KS Types - Sampling Plan for Accelerated Life Tests, etc.

The text in the figure explains the procedure adequately. Note that inspection is reduced by half provided a suitable quality level is maintained as indicated by consistently meeting the acceptance criteria. Note also that under certain circumstances of nonconformance, information is referred to Headquarters for decision as to the action to be taken. Provision is made in the inspection procedures for the acceptance of nonconforming lots of material when approved by Bell Laboratories. In the instance at hand, however, questions arise not only in respect to conformance of the one lot represented by the sample, but also in respect to product which may already have been shipped, and to product to be made in the future. The testing time element makes such cases a matter for consideration by specialists and adequate instructions cannot be supplied a priori to cover these cases.

One might ask why sample sizes of 6 or 12 have been selected as shown in the table. The answer is that together with the allowable defect numbers shown (0 or 1) these samples represent the minimum number that we can afford from a protection standpoint for the features in question, and the maximum which can be justified on an overall economic basis, insofar as our present knowledge enables us to determine these factors. It is always preferable, if it can be justified, to arrange for an AN of at least one, since with an AN of 0 any defect means nonconformance. We can do so with the first three items listed in the table. For the remainder, the sample size necessary cannot be justified and we do better to arrange for the special handling of those instances where a failure is encountered.

The technique described in this procedure is one which may be subject to revision as further experience is obtained. We are still to some extent feeling our way as to the best solution. The plan is definitely better, in any event, than reliance on the assumption that the process, which produced the component which proved acceptable in the "type" test, will continue to be satisfactory indefinitely with no surveillance other than by the usual end-test checks.

Wire Products

While most of the products involved in purchases of telephone supply items are best inspected by the method of attributes - all are inspected by this method for quality characteristics which are not quantitatively specified, i.e., "judgment" items - economies made possible by the method of variables sometimes dictate the use of this method. Consider, for instance, some of the wire products such as insulated electrical conductors, suspension strand, armor wire, and lashing wire. These products are usually submitted for inspection as coils or reels. For such requirements as tensile strength, elongation, adhesion of insulation and the like, tests are destructive and sampling is mandatory. Regardless of whether we consider each coil or reel separately, we are still usually limited to a sample of one or two specimens per unit since to take more would require uncoiling and recoiling and shorten the length in which the material is furnished. Under conditions where the distribution of the characteristic is known to be reasonably close

to normal, as it is in many cases, the product can be evaluated quality-wise on the basis of criteria expressed in terms of $\bar{X}$ and the range of reasonably small samples.

In the inspection of drop wire conductor, for example, measurements are made for conductor resistance, breaking strength, and elongation on one specimen from each of 10 randomly selected coils. Maximum or minimum limits, as appropriate, are imposed on the average of the ten results and an attributes criterion, AN = 0, on the limiting value for a specimen. Should the product give a first indication of nonconformance under these criteria, a second sample is inspected on an attributes basis in accordance with a double sampling table, the first 10 specimen results being included as part of the first sample under the table. The savings in inspection effort which are possible as compared with an initial attributes plan are appreciable when incoming quality is good.

It might be of interest at this point to cite an instance of what can be done in the way of real savings in inspection effort when we can get right back into the process. The Western Company manufactures very large quantities of drop wire in its own plant. Detailed analyses have been made by Laboratories from time to time concerning the magnitudes and variability of the quality parameters of this product. One of the important requirements is that there be a minimum bond of adhesion between the rubber insulation and the conductor. Proper adhesion insures longer life and helps to prevent slippage in the clamps which are used to suspend the drop wire between the telephone pole and the subscriber's premises. The insulation is extruded onto the conductor and vulcanized all in one continuous process. Operation is generally on a 24 hour per day basis and a number of individual extrusion machines are necessary to supply the required output. The process is excellently controlled with respect to individual machines, to separate daily shifts, and to seasonal and long-time variations.

It was formerly the practice to employ an attributes procedure for the inspection of adhesion in which two specimens from each of about 10% of the manufactured coils of drop wire were measured for this feature - some 18 to 20 thousand specimens per month under output figures approximating 165 million conductor feet per month. For quality assurance purposes, Laboratories requested monthly percentage failure results on 1,800 to 2,000 specimens, along with actual measurements of adhesion in pounds on 200 specimens per month. Under the current inspection procedures, developed as a result of the detailed analyses mentioned, the inspector measures normally only three sets of four specimens each per day - a total of about 250 specimens per month - and plots the results on a specially designed control chart. This is all the inspection made for this feature unless the results indicate lack of control, in which event the procedures call for the successive application of three separate sets of criteria, each calling for sizeable increases in inspection over its predecessor. Since each specimen is only a few inches in length, the current procedures call for the examination of less than a millionth of the wire under normal conditions. Furthermore all of the necessary inspection information is obtained

directly from regular shop inspections, and successive inspections which are normally applied by Western are eliminated entirely. While the savings possible with this plan as compared with the best of attributes inspection procedures are obviously enormous, it should be pointed out that the control type of inspection carried to the degree here indicated is possible only when product is very well controlled and at very satisfactory levels.

Automotive Equipment

Under the general classification of automotive equipment, the Bell System purchases a large number of items used for outside plant construction purposes, station installation and maintenance, coin box collections, etc. These comprise various types of bodies for mounting on automotive chassis, trailers, tools such as winches, pole derricks and earth boring machines, which are powered by the automotive engines, and accessory equipment. Inspection of this type of product is covered by a series of inspection instructions designed to provide for features peculiar to this specialized line of apparatus. As would be expected from the nature of the product, certain requirements involve a different order of processing accuracy than is the case in many of the other types of product referred to previously.

The component parts of winches, power take-offs, and boring machines, for example, must be made of carefully controlled alloys, machined to close fits, and heat treated to insure strength and durability. Production volume is generally not large enough to warrant the type of assembly line common to the production of passenger automobiles, with the result that production of individual lots is not essentially continuous from the standpoint of inspection treatment. Much of the quality in the finished product, furthermore, is the result of hand operations such as riveting, welding, and finishing. Truck bodies, for instance, are much more of a custom-made article than those products referred to before as hardware items.

Inspection procedures for this class of product may be divided broadly into two categories: a sampling inspection of component parts before assembly for the specified requirements such as material, dimensions, hardness, depth of case and finish; and a 100% detailed inspection of the completed product for assembly features, such as riveting, welding, locating, fitting, etc. including an operation test where pertinent. Needless to say, in these circumstances we find in the inspection procedures a minimum of sampling tables and a large amount of text describing the numerous checks to be made and detailed descriptions as to how to make them. Since many of the features depend upon the inspector's judgment, inspector training is an important part of the inspection planning.

Performance Per Dollar Indices

Some of the design specifications include requirements which are more satisfactorily and economically verified in a central testing laboratory. The verification may involve the use of special

mechanical or electrical equipment, the skills of a special technician such as an analytical chemist, or the more or less constant attendance of an inspector whose continued presence at the supplying plant cannot be justified. Luminosity and life tests on incandescent lamps, and life tests under specified load conditions on dry batteries, represent features which are better handled in a suitably equipped central laboratory. Western maintains such a well equipped and staffed laboratory for inspections of this nature at its New York Headquarters.

Determination of the performance index for incandescent lamps is an illustration of an inspection procedure which is designed primarily to ascertain quantitatively the quality per dollar of the purchased product. Inspection involves in this case the selection of a representative sample of suitable size, the examination of this sample for visual irregularities, and the application of a life test under specified line voltages, with measurements necessary to ascertain the average performance per dollar of the lamps represented by the sample. Since the labor cost of installing a new lamp, or replacing one which has burned out in service, is by no means an insignificant factor in the cost of illumination, it is necessary to take account of this maintenance cost as well as of the direct cost of the lamp itself and its direct operating cost in lumens per watt. A performance factor, P, is therefore calculated from measurements obtained on the sample and substituted in the relationship:

$$P = \frac{L \times H}{c + r + \frac{pwH}{1000}}$$

where P = Performance in lumen hours per dollar
L = Ave. lumens output at 70% rated life
w = Ave. watts input at 70% rated life
c = Contract cost of lamp in dollars
H = Ave. life of lamp to burn-out in hours
p = Power cost in dollars per KW hr.
r = Replacement or installation cost in dollars

A performance index is calculated for the inspected product by comparing the calculated P with the performance P_s of a standard lamp:

$$\text{Performance Index, } I = \frac{P}{P_s} \times 100.$$

Inspection For Design Information

Inspection results frequently supply important information which serves as a basis for revising current, or establishing new, design specification requirements. Regular studies of inspection results are made by Bell Laboratories, of course, to insure that the specification requirements are such as to permit the continuous economical supply of materials. In some circumstances, information needed for development purposes is not furnished in the most useful form by the current inspection procedures. This is especially true in those cases where the instructions, designed as they have

been to provide the most economical inspection methods, may call for results on an attributes rather than a variables basis. In such cases it is common practice to supplement the instructions by additional instructions or special addenda which remain in effect long enough to secure the necessary development information.

For example, the instructions covering normal procedures for the inspection of clay conduit call for attributes inspection on many of the dimensions controlling the satisfactory lineup of successive lengths of the conduit. The conduit is an extruded fired ceramic material used for underground cable installation and is furnished in 1, 2, 3, 4, 6, 8 and 9 duct forms. It is purchased from many sources advantageously located geographically from a freight standpoint. Because the manufacturing process has not been very well controlled, it has been necessary to permit fairly wide dimensional tolerances for the finished product. The dimensional variations cause difficulty in laying the material satisfactorily, and this is aggravated when product of two suppliers is intermixed as supply conditions may demand. Our development engineers estimated a considerable saving in installation costs to the Operating Companies if, by more exacting dimensional requirements, the interchangeability of the material dimensionally could be improved.

A special inspection instruction was prepared and data were secured by the inspectors and analyzed by the Laboratories. This analysis showed that a large part of the dimensional variation resulted from lack of control of the extruding die dimensions within a plant and from plant to plant. An approach to the suppliers, explaining the objective and discussing with them the shortcomings and desirable changes in their manufacturing processes by the introduction of simple control procedures, has enlisted their cooperation to the point where improved (more restricted) dimensional requirements have already been made possible, and further improvements are likely.

Auxiliary Inspection Information

Supplementary to each of the detailed procedures covered by the various inspection instructions are certain general procedures which are necessary to facilitate the inspections, to provide for the necessary inspection results information, and to insure the continuing accuracy of the results obtained. These are incorporated in the individual instructions or in general instructions which form a part of the complete inspection procedures applying to any given product. Their specific nature and purpose are as follows:

1. Evidence which can be associated with the product as to its acceptance on the basis of Western's inspection is usually desirable. The instructions specify the type of inspection evidence required, whether it be by tagging, stamping, sealing, etc., and where the evidence is to be placed - on the item itself or on the container.

2. Specification requirements which call for the use of certain materials, such as brand of paint, or the application of a certain sequence in processing, such as "form before annealing," or the

completion of processing after inspection, such as painting, and the like, are frequently accepted on the basis of certification by the supplier.

3. Each instruction delineates the type, quantity and form of the inspection results information to be reported by the inspector.

4. Each instruction has a general statement to the effect that the supplier will furnish facilities necessary for the inspections, and specifies special requirements in this respect when pertinent.

5. Separate instructions are provided to cover the method and frequency to be employed in checking the accuracy and maintenance of testing equipment, gauges, meters, standards, testing machines, etc.

6. Separate instructions are provided to help the inspector perform his inspections in the most expeditious fashion. Notable are those instructions which furnish tables or charts for converting an inspection result into terms directly associated with a specification requirement.

Conclusion

The foregoing illustrations of acceptance inspection procedures represent obviously a small fraction of those necessary to provide properly for the large variety of Bell System purchases. It is hoped, however, that even such brief description and comments as have been given will help to point out some of the many considerations necessary to the formulation of the best methods under a given set of circumstances. Where relatively little manufacturing information is available, as may be the case with new products, the inspection procedures must be formulated on the basis of whatever pertinent information the inspector can obtain before actual inspection experience with the product. The procedures are then set up with assured protection as the main goal. Modifications with an eye to economy may thereafter be introduced as the results of the initial inspections may serve to make these possible.

It is apparent that each procedure should be tailor-made, with the close inter-relationship between design, manufacture, inspection methods, use of the product, and commercial considerations ever in mind. These factors are constantly changing, with the result that the best inspection procedures can never be assumed to be completely stabilized. Especially in these times of material shortages and mandatory substitutions it is important to be on the alert to make sure that the procedures are modified as circumstances warrant. When inspection economies have been introduced as a result of knowledge of the underlying processes and materials, it is doubly advisable to anticipate any effects of changes in these processes and materials and to revise the inspection methods as necessary. It is apparent also that the inspection personnel must be well trained. So many of the specification requirements must be evaluated by judgment that an important element in the cost of the material as well as in its quality rests, in the last analysis, upon the judgment of the individual inspector. That the inspection

procedures and the personnel who use them have, in general, been well chosen is attested by the hearty endorsement of the whole arrangement by the many suppliers whom they affect.

CONSUMER-VENDOR RELATIONS IN CONVERTING TO MILITARY PRODUCTION

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Those of us who have been in electronics production during the past several years know that considerable latitude has been given the parts suppliers and assemblers. If the article had public acceptance, production was in demand. This did not mean a lowering of quality standards but it did allow cost reductions which benefited the ultimate user.

This electronics business is big business. From the shipping docks in 1950 came seven and one-half million television receivers, almost a half billion receiving tubes, fourteen million radios, and more than eight million cathode ray tubes. The special industrial and civilian electronics products resulted in many additional millions of dollars of business. A portion of this productive capacity must now be diverted from civilian products to military products. These military products include communication equipment of many types, radar warning networks, ground and aircraft fire control radar, sonar devices for submarine detection, mine detectors, radiation detecting devices and scores of other products.

Converting these manufacturing facilities to military production brings into being an entirely new set of circumstances. These are brought about by the requirements of the military users and the procuring agencies. While these new requirements are not often particularly difficult to meet, they do impose problems that the vendor and manufacturer must solve jointly. It does take concentrated effort, an understanding of each others problems and a determined will to meet the requirements imposed upon us.

For the purpose of our discussion this afternoon, I would like to have you think of yourself as being the Vendor and I will be the Consuming Manufacturer. When the consumer places an order on the vendor, the new circumstances associated with military equipment immediately brings forward a multitude of problems. From the standpoint of the vendor, these problems cover such things as greatly tightened specifications, increased investments for capital equipment, detailed test and inspection routines, material certificates, specific quality control procedures, certification of welders, and many others.

From our, the consumer's standpoint, we are immediately faced with higher prices, questions of vendor compliance, lengthening deliveries, additional component testing, checking vendor capabilities, and many others. Perhaps the greatest single problem that is facing us, as the supplier of the equipment to the military, is the question of reliability of our components. In our commercial production we expect to find a small percentage of customer complaints caused by random component failures. Warranty adjustments on traffic items can readily be handled by distribution systems. Major equipments can be serviced directly by the manufacturer. While such failures are an irritating factor to both the user and manufacturer, usually the remedy can be affected in a very short time without serious consequences.

Military equipment failures are likewise a cause of irritation but the lives of people are frequently dependent upon proper functioning of the equipment. Perhaps the existance of a city may be jeopardized by a random component failure. Reliability is exceedingly important. I do not believe

this can be overemphasized. For our own security, we must keep ahead of the rest of the world in development of new and better devices that operate reliably, day after day.

Let us examine two component part examples to illustrate this point. Almost every other part or component we will face a similar, although perhaps a different, set of circumstances. First let us examine a hollow casting which will be subjected to internal pressure. In the electronics military production, many wave guide fittings, etc. are used which require operation under pressure even though the pressure may be relatively small. Very minute leaks through porous castings can not be tolerated. The machining of the flat surfaces must permit an air tight joint even though the casting may be subjected to vibration and radical temperature changes.

To meet the casting specifications, process control is probably more important than 100% or statistical sampling inspection. For this reason, initial samples, prior to the release of the production quantity, are almost always required to examine the vendor's casting techniques and to verify the drawings. Perhaps X-Ray, zyglo, magnaflux, strain analysis, chemical analysis, and other checks will be called for on the sample and on a specified schedule on the production lot. These tests may not be difficult to make but the specifications usually are written so tightly that we are approaching the limits of the art. Therefore, detailed tests become exceedingly important to verify casting quality.

Or, let us take the example of a small Servo Amplifier which you as a vendor may produce for us as a consumer. Seemingly, we as a consumer impose many unnecessary restrictions upon you and in most cases do not allow even a minor local improvised technique. We specify what standard shop tolerances or shop practices must be adhered to. We will specify materials in great detail requiring advance approval on even minor items such as assembly hardware, if it is not in strict compliance with the drawings. Approval of all parts and components must be obtained in advance even though you know that the suggested alternative is equal to or perhaps better than that required by the purchase specifications. Standards for welding, riveting, hardware, wiring methods and soldering are carefully spelled out. Assembly and adjustment, finishes, painting, cabling harnesses, paint markings, packaging and many others are spelled out in great detail perhaps even farther than the controlling military specifications. This, of course, is in addition to all electrical specifications which might be called for.

On the surface, this seems like "Gilding the Lily". Look at some of the reasons why we require the adherence to such rigid specifications. First, let us look at the casting I mentioned a few moments ago. This casting will very likely be used in modern aircraft operating in the sub-stratosphere. Within minutes the equipment will be subjected to temperature variations from say 115° F to -60°F. The pressure will vary from 15 pounds per square inch to only a few pounds per square inch at that altitude. The equipment will probably be placed in such a position in the aircraft that accessibility in flight is out of the question. Therefore, the equipment must be so designed as to withstand altitude, humidity, temperature changes, vibration and perhaps even dust and explosion shocks without further adjustment. The military specifications in some cases are not as stringent as actual service requirements.

Production reliability is of paramount importance and the cost in such cases is usually secondary. Failure of the electronics equipment may mean failure of a mission or in case of combat, conceivably failure of an entire campaign.

In the case of the electronic subassembly, we can assume that this device will also be subjected to altitude, humidity and temperature changes and reliability again will be of utmost importance. Maintenance at forward bases can correct only the most minor malfunction, thereafter, equipment must be returned to a rear area repair center. Here non-uniformity of a product cascades the maintenance and parts stocking problems to such an extent as to make a complex piece of equipment almost useless unless the most rigid standards are adhered to. Standardization and interchangeability are necessary because the technical skills required are becoming greater and greater or by comparison the availability of skilled repair craftsmen is becoming less and less. Military electronic equipment is becoming exceedingly complex.

So far I have mentioned only the existence of a few problems and cited some of the reasons why we as a consumer are demanding ever better and more reliable products built to tighter and tighter specifications. Obviously, the user, or the Government, is also vitally interested in such problems and their solutions. Their specifications are likewise becoming more stringent and their inspection more and more rigorous to the point that we must pass along many procurement and testing specifications under the terms of our contracts.

New contracts must meet military specification MIL-Q-5923 (USAF) under the heading of "Quality Control of Aircraft and Associated Equipment". I would like to point out a few general statements in this specification which shows that vendor-consumer problems must be jointly solved under the procurement specifications. As an example, I would like to quote -

> "All supplies manufactured within the contractor's plant, or procured from any other source, shall be subject to sufficient inspection to assure conformance with contractual requirements. Tests shall be conducted on representative samples of materials in the prime contractor's or subcontractor's facilities or in suitably equipped, privately owned or commercial laboratories acceptable to the Government Representative. Such test reports, however, may be subject to further verification by the prime contractor to the satisfaction of the (Government) Inspector."

Not only is the military interested in the end product, it is also vitally interested in the reliability and uniformity of the product. To this end, the specifications state "The contractor shall prepare a written description of his quality control system which will include an organization chart and a plant layout, with the location of inspection stations indicated. The written general description shall include the inspection procedure, covering all phases of the inspection operation. Check lists, operation cards, standard forms, and other material used in the contractor's quality control system shall be included as part of the general description.". I mentioned a moment ago, we have no alternative but to pass some of the detailed inspection requirements on to you as a vendor. We are specifically charged in the procurement by the following:

"Prime contractors shall insure that the provisions of this specification are made binding on all subcontractors and suppliers. When source inspection is conducted by the government this shall not be considered as a guarantee of final acceptance nor shall it relieve the prime contractor of the responsibility to furnish an acceptable article. The Government reserves the right in any case to require additional tests to assure the articles are acceptable. The prime contractor shall be responsible for assuring that any subcontractor is fully qualified to perform any special process required prior to requesting Government approval or certification. The prime contractor shall be responsible for initiating corrective action with his subcontractors and suppliers on discrepancies found upon receipt of supplies, whether or not such supplies have received Government source inspection." From this, it can be seen that not only we as a consumer but the Government as a user will take steps to obtain satisfactory materials.

The quotations cited are from regulations governing Air Force procurement. The Navy and Army procurement specifications are very similar. For a small vendor, these regulations pose a serious problem at first. In many cases, however, a careful reading of the applicable specifications will show that you as a vendor are also protected when the quality control requirements are met.

How can we minimize our problems as vendors and consumers? A detailed study of the specifications is usually the first constructive step. Once we understand the specifications, we must be certain that our products actually do meet the final specifications imposed upon us. This may mean additional investment in the form of more precise measuring equipment or better production tools. To make sure that such equipment will actually meet the specifications, almost every process has an applicable governing military document stating in explicit terms what is required. These documents too, must be studied in order to have compliance with the specifications. Once we start on production, we seem inevitably bound by controls of some sort or other whether the measurement problem is chemical, electrical or mechanical.

Not all of the electronics industry is or should be converted to military production when we are building up for a defensive position. The "pay as we go" economy requires a substantial civilian consumer goods output. To meet the tax load, it seems obvious that the taxes collected from the workers on military production cannot fill the Federal Treasury since it merely returns to the Government a portion of what the Government is spending for these products.

Electronics is a factor in our national economy when the materials are traced back to the mines. The units of labor expended from the raw material to the final product provide a living for many, many thousands of families. To maintain a stable economy requires that at least a portion of this productive effort be retained in non-military production.

This also, will cause problems in consumer-vendor relations. I believe the role of Quality Control will be increasingly important. To maintain this "dual economy" will require production in addition to the present civilian production. Some of this can be achieved by increased efficiency, some of it must be obtained by expansion of existing facilities. Improved efficiency does not mean fewer people in your Quality Control organization.

The number of skilled workers available is probably limited. The control of quality during the initial period of utilizing new help is one that affects military and civilian production alike. A reduction in the overall quality level can be tolerated only in a few places. The consumer will buy the product that represents the best value for his set of conditions. A joint consumer-vendor program may be a partial solution when material substitutions are necessary for civilian production. This involves careful study by the engineering departments and alert quality control groups in both organizations. Purchasing agents must be brought into such a plan and at times manufacturing and planning groups will be involved. In other words, a catalog description may change from time to time and additional communication between the vendor and consumer will be necessary.

Not only will the production skills be diluted, the engineering staffs will also be diluted by this expansion. This poses problems for both the vendor and consumer. The vendor feels the impact in incomplete specifications and constantly changing specifications. The consumer feels it by item mis-applications, non-conformance with previous standards and, sometimes with totally unacceptable components. Reliability of components is now a real problem and this problem will surely not decrease.

Consumer-vendor problems will increase while converting to military production. The problems of maintaining satisfactory quality on civilian goods will probably increase if use of scarce items are further restricted. I do not believe that the consumer or the vendor can independently solve all problems caused by the demands of military production. Additional communication between the two seems definitely indicated. These communications will probably be at several levels within the respective organizations.

Quality Control organizations must contribute an ever greater portion of know-how by assuming the management function by which the overall quality of our respective products and services can be controlled and assured.

GAGING TO FIND THE FACTS

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During the past few years a great deal has been written about the subject of Statistical Quality Control both in book and magazine article form, and there is no question that a great deal more has been spoken. Although no one person has read or heard all of this matter and therefore no true index of the phases of the subject is available, it is reasonable to say from personal observation of a random sample that the emphasis has been on the statistical phase of the overall subject. Occasionally this emphasis is so great that those of us who are responsible for quality control efforts are inclined to reach a state of mind where we cannot find the forest because of the tree. Therefore, it has become the feeling of some of us that we should take a little better look at the forest, or at least a portion of it. One of the most important parts of this forest is the problem of gaging and instrumentation. This covers all of those instruments, gages, meters, machines, and any other means for producing the facts concerning a product or process characteristic regardless of its nature. Unfortunately, it is beyond the scope and qualifications of this talk to discuss the problem in detail. However, as gaging and statistical quality control are and must be hand-in-glove relative to the overall program, it is proposed to discuss a few of the pertinent general points on their relationship which may clear the air for you, and help qualify you more highly for your task.

It can be positively stated that we can have a reasonable quality control of a product or process without statistics, but we cannot have effective statistical quality control without intelligent gaging. We have found in recent years that a new and very effective tool is available, but we should not in our haste to use it throw away those other useful and indispensable tools that are an accepted commodity -- gages.

Let us look a little more closely at the tie-up between gaging and Statistical Quality Control so that we may understand a little more fully why a knowledge of gaging and the ability to apply it properly are so necessary. In practically any manufacturing process you can think of, certain elements are involved. One of these is commonly known as a specification - any one will serve our purpose here. In most cases this specification will contain a statement that certain quantitative characteristics must be met for acceptability of the product.

Immediately then, since we are required to control those characteristics demanded by the specification, we have a gaging problem. This problem must be analysed because - as the old saying goes - "In order to solve a problem we must first know what the problem is." Perhaps the first questions the Quality Control Engineer should ask himself on surveying a specification to be controlled should be, "Is the quantitative characteristic under scrutiny critical? Does it seriously affect strength, service life, function, appearance, saleability, etc.?" Should the answer be in the affirmative, we generally conclude that whatever gaging is applied to the job of analysing the quantity, it must be good. It may be said at this point in the procedure, having selected a gaging method believed to be adequate, that quality control is now in effect. However, if

we are in the Statistical Quality Control business, our job is not quite finished particularly in the case where we choose to operate a control chart or a variables sampling plan. So in this point of the analysis of the problem we are faced with the question of how much better than "good" should our gaging be. Unless we have had past experience with very similar problems our decision on this matter must frequently be postponed until we can actually get our teeth into it and gain some experience. This may sound somewhat like putting the cart before the horse, but the situation is this - For statistical purposes we must know the facts and the facts must be accurate. Lacking the past experience we are in the unfortunate position of knowing nothing about the inherent variability of our quantity and this is the foundation of Statistical Quality Control. To satisfactorily operate control charts and sampling plans it is necessary to break this inherent variability into sufficiently small segments of measurement so that the variation can be detected by our gages and recorded. This is an extremely important factor from the gaging point of view and it is obvious that the man in charge of this job must know something about gages. It can be argued, of course, that the Quality Control Engineer can employ the services of a gage expert. This is very true in some particular cases, but it is not believed to be the most efficient method for the ordinary everyday job.

Knowing that the gaging is not definitely established until some facts are obtained, let us look at a sample case where it is desired to set up Statistical Quality Control on a new job and see what can happen when gaging is not thoroughly examined. A specification for temperature of a chemical solution is given as 200° ±5° F. For purposes of control it is elected to use a recording thermometer which has recording graduations readable only to 5°. After installation it is found that the thermometer produces temperature readings of the solution of 195, 200, and 205 in varying sequence over a period of time. For statistical purposes this range of readings is not enough, and to analyse our results based on these readings would be foolish as we would probably come out with a statistically incorrect answer. The truth of the matter may be that the temperature may be varying somewhere between limits of 197.5 and 202.5 or it may be varying between 192.5 and 207.5. We don't really know as we do not have the facts. The former variation is OK, but the latter is not. From the statistical angle the gage selected for this job was a failure, and not even too satisfactory for ordinary control.

For Statistical Quality Control purposes a more proper gage for this job might have been a thermometer that was capable of providing at least seven and preferably more different readings of the total temperature variation of the solution, i.e., increments of at greatest 0.5°. It is generally felt that a breakdown of twenty increments should be considered a maximum for effective results. Your goal can therefore be a happy medium of about fourteen. Note that the spread of the specification is not considered. There are innumerable instances of this sort occurring all the time and, fortunately, where experience is available cases where the proper method of gaging can be selected at the first attempt. This is a very simple example of the type of situation that requires an intelligent analysis and a good gaging background. A better approach will be pointed out in a minute.

Going back to our example for a moment, it was pointed out that due to the coarseness of the instrument we are unsure of our control - the possibilities being that the process is meeting the specification satisfactorily, or is borderline, or is no good. You may well ask now - "What happens

if no thermometer is available?" This problem is prevalent in many cases, and cannot be answered here and obviously places the burden of solution on the man doing the job. The main interest is to find the facts in this or any other typical situation. Taking the easy way out, let us assume that a plain, ordinary, mercury thermometer is at hand which can be read to an accuracy of 1°, and estimated closely to 1/2°. Now, by taking a series of readings with this thermometer over a period of time and at various locations in the solution tank we can obtain our facts and analyse them by statistical methods. Once it can be determined that the temperature of the solution can be maintained in a state of control and within the limits of the specification our problem is over. For then we can set up a control chart and by taking readings at greatly reduced intervals insure our control at a very low risk level with a minimum of time required to do the job. It would have been well for the Quality Control Engineer to set up the gaging in this manner in the first place and thus saved the cost of procuring and the inconvenience of installing a recording instrument of the type selected.

The foregoing example is typical of the type of problem facing the Quality Control Engineer. It is a crude example but purposely so as it serves to bring out two factors in our Statistical Quality Control gaging tie-up. Both of these should become a habit in the daily thinking of the Engineer. The first point is that he must find out, if possible, what the inherent variability is of the characteristic he wishes to control before a final decision can be made on the gaging method. This can frequently be done with available equipment although it may be a long and laborious procedure. The second point then follows and consists of whether or not the type of gage finally selected for the job is available and can it reduce the variability into a sufficient number of measurable increments for statistical handling. With this approach, and with successful results on both points, the remainder of the control problem is routine.

Up to this point the comments have obviously centered about the variables type of measurement. It is fair to ask why since we do have such things as attribute sampling plans which are quite valuable in the Statistical Quality Control scheme of things. Attribute sampling has been and is being used extensively and successfully today. However, it is advisable to reiterate a statement which most of you who have been exposed to Statistical Quality Control have heard since it has a definite bearing on the subject under discussion. The general thought contained in the statement is that a variables type of problem analysis will provide a great deal more information concerning the characteristic than an attribute analysis, and in shorter time. Furthermore, it is sometimes true that in the long run a variables sampling arrangement is more economical than the attribute. It is always true where the determination of the characteristic requires destruction of the part.

Another gaging problem that arises occasionally and must be overcome by the Quality Control Engineer is that of the necessity of using gaging of questionable accuracy. To more clearly define this sort of thing, a temperature recording device capable of recording smaller increments of temperature might have been selected for the control of the chemical solution and can serve as a good example if we assume that the instrument has the fault of wandering from a fixed reference temperature. This is a very disconcerting faculty particularly where the degree of variation is a sizeable portion of the specification range so that the re-

sultant total variation of the gage and process is beyond that range. If this fault is known the immediate conclusion is that the gage cannot be used. This is not true. There is a statistical solution to the problem which makes the gage as good as new at very little cost. First, it is necessary to check the variability of the gage with respect to a fixed reference value by taking fifty readings over a sufficient period of time to provide a good random sample of the gage variation. These readings may then be analysed statistically to determine the standard deviation of the gage, and also to find out if the variation appears to be approximately normal. The gage can now be set up for use and process temperature readings taken in the usual manner and the standard deviation of the total variation calculated by the same method used for the gage. To determine the true variation of the process temperature statistical subtraction is used. This is represented by the simple formula -

$$\sigma_{True} = \sqrt{\sigma_{Total}^2 - \sigma_{Gage}^2}$$

The effect of gage error is demonstrated in the following Table.

Gage Variation in % of Total	True Variation in % of Total
10	99.5
20	98.0
30	95.4
40	91.7
50	87.0
60	80.0

Thus it is demonstrated that very erratic equipment can be used to obtain results sufficiently accurate for most practical purposes. Until the gage variation exceeds about 30% of the total its elimination is of no particular value. It is cautioned that this method applies only where the variation of the gage is uniform about a fixed reference. Where the gage does not hold to a mean of the reference value this analysis is of no use.

Although only two of the many gaging problems which confront the Quality Control Engineer have been discussed here, it is felt that enough has been said to point out the hand-in-glove nature of the Statistical Quality Control and Gaging business. The manufacturers of all types of gages, instruments, etc., are doing a wonderful job in assisting the development of our phase of the statistical field, but it must not be forgotten that they also need your help, and the more you progress in the art of intelligent gaging the greater will be your value to both your profession and the gaging industry.

ESSENTIAL DESIGN QUALIFICATIONS AND CORRECT APPLICATION OF GAUGING DEVICES NECESSARY FOR EFFECTIVE QUALITY CONTROL OF SCREW THREADS

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Quality Control is referred to in this article in its broader aspect to include Statistical Quality Control. This article is submitted for purposes of contributing to the subject of Quality Control in one of its narrow yet important fields - Screw Threads. It is hoped that it will eliminate some existing misunderstanding concerning Screw Thread product specifications, their inspection and gaging devices, and the application of these devices. Further, it is hoped that this information will relieve certain existing tension points and directly enhance the effectiveness of Quality Control in this complex and specialized field.

It is essential to recognize that there are many involvements in the subject and application of Quality Control, and to emphasize the absolute necessity for carefully considering the place, purpose, and relative importance of any single phase in terms of the overall Quality Control problem. It is equally necessary to adopt the correct type of equipment and to apply it at the proper time and place, and in a manner that is most practical and effective for the item or projects to be controlled. It must be remembered that the chain is no stronger than its weakest link, and this is equally true in a Screw Thread Quality Control program.

It is hoped that objectives will be reasonably well accomplished through the frank consideration of the subject of this paper, which is: ESSENTIAL DESIGN QUALIFICATIONS AND CORRECT APPLICATION OF GAUGING DEVICES NECESSARY FOR EFFECTIVE QUALITY CONTROL OF SCREW THREADS.

A superficial consideration of the subject of Screw Threads as related to the broad field of Quality Control could understandably result in the deduction that there is but very little to it. The Screw Thread is standardized on a national basis - has been for about thirty years - and on an international basis for nearly three years. In the matter of gages for both external and internal threads, there have been standards for Ring and Plug Gages for about twenty years - even for Setting or Check Plugs. Statistical procedures as to sampling plans and related details are widely understood though not too broadly applied as yet to Screw Threads.

The standardization of Screw Threads attests to their importance and this has been of tremendous technical and economic advantage to industry. However, standards lose much of their basic value when they tend to stagnate thought and action and exercise an unprogressive influence through the traditionalistic atmosphere which it is inclined to radiate. This article does not confine itself to consideration of adopted standard design of gages - instead, it intentionally includes other non-standard devices which have conclusively proved to contain superior characteristics and qualifications necessary and able to enhance the movement of Quality Control, both conventional inspection and statistical. Obviously, we cannot completely and adequately prescribe 1951 Quality Control for Screw Threads with gages of 1920 vintage - probably not wholly adequately with gages even of 1951 newness; however, the chronological synchronization gives far greater assurance of more

acceptable results.

Other facts which dispel the hope of simple and singular disposition of Screw Thread Quality Control is the wide size range of the product - from instrument screws smaller than one-sixteenth inch in diameter with pitches finer than one hundred per inch, to retaining and adjusting nuts over twenty inches in diameter. The combinations of thread forms, helix angles, etc., present an equally wide variety of problems. This variety and range present problems both in manufacturing and in inspection methods and equipment; quantity is also an influencing factor both in methods and equipment.

Additional complications of the means and methods of Screw Thread Quality Control are where the screw is the centralizing type and the condition imposed by the alignment feature affects particularly the dimensional importance of one element from the standpoints of either or both size and tolerance. Another increasingly important influence is that of the relationship between the thread and a coacting surface where concentricity or squareness is a factor.

However, despite these various conditions in Screw Threads the specific problem of their Quality Control remains the same because the elements and conditions requiring control are substantially identical. It might be advisable at this point to state that this article deals particularly with "fastening" threads, while lead screws and other special purpose threads are similar in most if not all details, their special application generally involves added emphasis on specific elements - both in manufacture and inspection. Therefore, they should be treated separately. Also, the subject of various taper threads is purposely omitted. These threads become confusing when dealt with at the same time as the fastening types; further, they are definitely a full subject in themselves. There is, however, much in common in the basic problems of Quality Control of straight fastening threads and the taper type of threads, including Dry-seal, both in gaging equipment and its application.

The problem of Quality Control of Screw Threads relates specifically to the "elements" of Pitch Diameters, Lead, and Angle, and to such "conditions" as roundness, straightness, uniformity of helix, bruised, and imperfect starting threads, etc. As previously stated, these screw thread elements and conditions may further involve such factors as concentricity, squareness, etc., with coacting surfaces of the threaded piece.

The technical function of Screw Thread Quality Control devices is to determine that all "elements" and "conditions" are within overall product dimensional specifications, which presumably, are necessary to assure (1), assemble-ability of product, and (2), required functional performances. In other words, the prime purpose of gaging devices is to make it possible and safe for the product manufacturer to take 100% of the tolerance the product engineer allows - but not 101%.

In the case of external Screw Threads the fundamental equipment necessary and adequate for this determination is the simple and familiar combination of a Go Thread Ring Gage and a Thread Micrometer with its conventional Cone and Vee anvils. However, this is not the ultimate in equipment either technically or economically; there are many Tiffany grade gages and comparators available - the determination as to which

is most practical is frequently but a matter of economics.

The Go Thread Ring Gage is a "functional" gage - actually a master nut or component. It assures that the physical dimensions of the Screw Thread, its separate elements and of all elements in combination, are within overall and cumulative size or retain the requirement of assemble-ability. Actually, the Go Thread Ring Gage merely determines that the combination of errors of thread elements, plus the presence of other undesirable conditions as out-of-round, taper, bruised, and imperfect starting threads, will not prevent the screw from assembling with its component. The Go Thread Ring Gage does not determine the dimensional accuracy of a screw - it merely determines its assemble-ability.

Conversely, the Go Thread Plug Gage has an identical relationship to the internal thread. It determines assemble-ability not dimensional accuracy. While the deficiencies of the Go Thread Ring and Plug Gages have been pointed out and purposely emphasized, it is true that they do adequately meet their primary function which is to determine assemble-ability. In fact, they perform this requisite so effectively that they deserve to be regarded as standards for all similar purpose and competitive (functional) gages and comparators. Therefore, all other non-standard and "functional" type Quality Control devices are incorrect and inadequate if they accept and pass as satisfactory for assemble-ability Screw Threads which do not agree with the Go Ring and Go Plug Gages which definitely are the final reference and authority for this quality. Summarily, Go Thread Ring and Plug Gages are simply cumulative and functional type gaging means for determining only assemble ability of product.

A companion to the Go Gage, generally referred to as a Not Go Gage, is required for determining that the "size" of the Screw Thread, specifically its tolerance for pitch diameter, has not been exceeded in a compromise for existing errors in the thread elements of lead and angle, or because of the presence of the "conditions" previously referred to and which may affect (sometimes deceive) the actual gaging for (P.D.) dimension.

The prime function of the Not Go Thread Ring Gages is to determine that the pitch diameter of the Screw Thread is not undersize at any point. This means that if the screw is out-of-round it must be within pitch diameter limits at its smallest (out-of-round) point. Further, it means that if the screw is tapered it must also be within the specified Pitch Diameter limits at its smallest (taper) point. Its function is to detect the minimum size of a Screw Thread at any point or part of the thread. From an engineering point of view the standard AGD Not Go Thread Ring Gage is entirely incapable of performing its intended function, and it may be used only when its inadequacy can be intentionally ignored, or when the nature of the product is such that "stretching" of tolerances is purposely tolerated. Its use should be prohibited for checking screws where human safety is involved.

Conversely, the same type and degree of inadequacy is present in the design of the standard AGD Not Go Thread Plug Gage. However, the usual methods of producing internally threaded holes substantially minimizes theoretical limitations and consequences of the fundamental gage design fault. This minimizing of a defect is not to be construed, however, as suggesting that the use of presently available improved design of Not Go (maximum P.D.) plug gages and comparators should not be encouraged, or that further development in this field should not be made. The need

for the contrary should be stressed, and particularly in those threads where human safety is dependent upon secure fastenings.

Fortunately, however, the incorrectness and inadequacy of the Not Go Thread Ring Gage may be fully avoided by substituting the elementary and effective principle of the Thread Micrometer with its "line" contact Cone and Vee anvils, which is available in many forms. From an engineering standpoint it is obvious that only this principle (the Thread Mike) can correctly determine the minimum pitch diameter of the external Screw Thread, which is the true and intended function of the Not Go Thread Ring Gage.

Summarily, the purpose of Go Thread Gages is to determine the assemble-ability of Screw Threads, the singular function of Not Go Gages (through minimum and maximum pitch diameter size control of external and internal threads respectively) is to assure that the product will adequately meet its functional requirements in operation. The latter is of vital importance where the safety of human life is involved, as in aircraft mechanisms. Incorrect Go Gages may result in assembly difficulties; incorrect Not Go Gages enable functional product failure may cost human life. This is an instance where the stark facts demand sober reflection.

In addition to conventional plug and ring gages and their respective functions, and the extent to which they meet or fail to meet their intended purpose, it is both advisable and necessary to consider other newer yet commonly used and tested non-standard Screw Thread Quality Control devices. It is immaterial as to whether these devices are fixed type gages or indicating type comparators; the essential point of consideration and comparison is end results, and this is accomplished by focusing attention on the heart of the device - the gaging contact elements. Whether for gaging internal or external threads, these various elements may be classified as functional or peripheral type (as Ring Gages), or as line contact type (as Thread Mikes). (A measuring wire has a point contact with the thread being measured. Its use on any but ground and hardened work, except under special conditions, is impractical and even unfair.)

The Go Thread Ring and Plug Gages are functional type and have peripheral contact. Substantial approximations to this ideal are obtained with devices having segmental type gaging elements (internal or external) which, essentially, are actually segments of thread ring or plug gages; also, the multi-ribbed tri-roll type devices (particularly on external threads), are intended to approach the results obtained with the peripheral contact functional check of the Ring Gage. To repeat and emphasize, the final answer for all types of Go (assemble-ability) gaging means and methods is the Go Thread Ring and Plug Gages. Obviously the agreement between non-standard gaging devices and standard Go Ring and Plug Gages is directly proportional to the similarity of these gaging elements and their resulting contact with the Screw Thread. Unfortunately there are designs of Go Gages which cause conflict, and various types and amounts of allowance must be made in their use to obtain required conformity. The Thread Micrometer which has the basic design qualifications for this purpose for external screws is available in many line contact forms in both fixed and indicating type gages; flat or crowned Cone and Vee anvils, and annular ribbed rolls being most common. The counterpart gage for small internal threads is the expansion type plug gage and comparator with segments having reduced axial contact to

avoid lead interference, and with modified profiles to obtain a shorter line contact on the thread flank. Expansion type bar gages with Cone and Vee elements, in both pin and roll design, are available and are successful for larger size threads.

At this point it is probably advisable to summarize certain stated facts and attempt to draw some specific conclusions as to the status of gaging devices available for Quality Control of Screw Threads:

First, there are several types available.

Second, there are essential differences in design with sometimes conflicting differences in gaging results.

Third, the confliction that exists between gaging devices of different designs can be substantially reduced by recognizing the fact that the Go Gage is primarily a functional check, determines assemble-ability only, that the final authority for all non-standard external and internal gages and comparators is the conventional AGD Go Ring and Plug Gage, and that other gages must be used in a manner that reconciles known differences.

Fourth, that the function of the Not Go Thread Gage is to check pitch diameter only, and that the closer in principle it is to the Thread Micrometer the more accurately it will serve its intended and required purpose. As a consequence of this known difference in gaging results between (equally accurate) gages of different design - especially when the product nears the argument zone or tolerance limit - the product manufacturer frequently resorts to what might correctly be called the "protective" system of tolerances, i.e., limits substantially inside of the buyer's specifications, or to the "duplicating" method which is to determine the customer's method of inspection - both equipment and system - and either duplicate this system or purposely use a more critical one. In either event the product manufacturer is actually reconciling unequal gaging devices instead of producing parts according to specifications.

Fifth, conventional Not Go Ring and Plug Gages cannot accurately perform their intended function.

The responsibility of the gage manufacturer primarily is to design and manufacture gaging devices that correctly serve the intended and required purpose. However, the very desirable competitive phase of free enterprise necessarily results in design variations with unavoidable conflictions in gaging results. Therefore, the critical analysis and comparison of available gaging equipment by the user is a definite necessity. Ignorance of gage inaccuracies or limitations does not excuse or correct incorrect product. Another reason for necessarily careful study of gaging equipment by the user is to assure that the gaging equipment is used for the purpose and in the manner intended by its manufacturer; the user must realize that any equipment will probably give incorrect answers if improperly used.

In conventional inspection of ordinary Screw Threads the conflictions in gaging results due to variations in gage and comparator design seem to have become accepted as inevitable, and few problems arise, which, with the long practise and required manipulation, are not within the area of arbitration and adjustment. However, the present industrial expansion will unavoidably result in greater numbers of unfamiliar and less compromising intra-plant associations, and probably a greater degree of

necessity to conform strictly with specifications. These facts alone make necessary a clearer understanding of Screw Threads and their inspection. Of far greater importance, however, is the forward moving science of Statistical Quality Control which necessitates not only a more exacting knowledge of various gages and their comparative results, but it actually requires further development and more effective use of gaging devices which will gage product more exactly, with greater convenience, and with more precise and complete information. Obviously, the entire Quality Control program in a plant may be severely penalized because of the fouling up that could occur through improper Screw Thread gaging devices, i.e., gaging devices incapable of gaging correctly. Certainly the advantages and validity of the control chart and system are tremendously discounted when they are made with devices that tell either an incomplete or an incorrect story. Therefore, it is in the prime interest of Quality Control in its newer and more profound aspect that the merits and demerits of various gaging devices be clearly recognized, and that gaging devices be correctly applied. Though no specific mention is made of optical projectors in this article as Quality Control devices, it is well known to all experienced production and inspection personnel that they are an indispensable piece of equipment as supplementary to gages and for analytical check, particularly (angle) form and lead of product threads - as well as for tools, taps, dies, etc.

There is a permanent leaning merger between gaging equipment and the control chart; they are vitally dependent upon each other; they sink or swim together. Only equipment that will gage correctly and which can be and is correctly used can produce a correct chart; and only a correct chart enables the diagnosis of product and operation which will result in improved quality, lower costs, and other desired and required advantages. The fundamental fact to realize and be guided by is that it is the correctness of each single point on a chart that determines the accuracy, value, and validity of a chart. Furthermore, it is essential that we remain constantly mindful of the fact that only substantial progress in successfully applying it will sustain and justify Quality Control as the authorative and respected force which our critical industry requires for maximum effectiveness of operation, and if Quality Control is to serve its purpose and receive Industry's blessing. Statistical Quality Control charts should always specify the exact type of gaging equipment used for a specific inspection operation. For example, in checking the thread of an aircraft stud: 1, assemble-ability check: Johnson RING-Snap Thread Comparator, Model BG, 5/8" segment thread length; 2, Pitch diameter (functional fitness): Johnson ROLL-Snap Thread Comparators, Model CN.

No. 1 Operation gives the functional (Go Ring) check, determines interchangeability; No. 2 Operation gives the pitch diameter only (Thread Mike) check, determines safety of screw in operation.

While Comparators were mentioned in the example it is obvious that the same specific reference to type of gage is necessary even if elementary type Go and Not Go fixed limit gages are used.

Another increasingly important consideration is introduced by the use of indicating type comparators. As previously pointed out, two distinctly separate gages or comparators are necessary to assure both assemble-ability and accuracy of external and internal Screw Threads. In the case of comparators for the external thread, one comparator gives a cumulative reading (assembly size), the companion comparator gives only

a pitch diameter size reading. Errors in lead, angle, helical uniformity, etc., invariably cause the reading of the "cumulative" comparator to be somewhat larger than the singular element P. D. comparator. In important precision parts, this "differential" reading (the difference in readings between the two comparator indicators) actually measures (and grades) the quality of the screw, and this increased information and added measurement is fast being recognized as an important element in screw thread inspection and analysis; also, it is extremely valuable in diagnosing machine and tool conditions, and operator performance. In some instances, it is established that the allowed differential reading cannot be greater than 50% of the total P. D. tolerance; i.e., if the P. D. tolerance is .0030, the maximum differential reading cannot exceed .0015. This is particularly important in stressed assemblies, also, where vibration is a factor, where in both cases, each thread must carry its share of load. The differential reading analysis is also of considerable aid in obtaining uniformity of drive in interference thread fit assemblies.

It would be a serious omission to neglect mention of urgently needed improved means to set and check more recently developed non-standard comparator type gaging devices. The present standard Setting Plugs were designed about twenty years ago, and with particular reference to the (AGD) truncated type were and are quite adequate for the fixed type gages then and now commonly used: Thread Ring and Thread Snap Gages. However, the increasing use of comparator type gaging devices with moveable gaging elements makes it absolutely necessary to use a more informative plug. First, this plug should provide for the entirely different conditions obtained when moveable instead of fixed position gaging elements are used. Second, they must enable a more practical means for determining the nature and degree of wear of the comparator gaging elements. In some precision parts inspection it has been necessary to standardize allowable gage wear to obtain uniformity and agreement in gaging results between vendor and buyer, and to establish a wear limit for determining the exact point of need for correction or replacement of gages or gage elements.

In conclusion, the Quality Control program in all its detail should be established by the product manufacturer - not by the gage manufacturer Sampling plans suitable for product, production, use factors, and all other conditions involved, as well as the selection of gaging equipment, whether for variables or attributes methods of control, should also be the undivided responsibility of the product manufacturer - not the gage manufacturer.

However, it should be stated, principally as a reminder, and without fear of exerting undue or improper influence particularly on the product manufacturer, though the buyer of his product also has a (somewhat different) control problem, that Quality Control is essentially the systematic collecting, interpreting, and acting on facts. Logically, therefore, the gaging device which gives the most and best information required (for the chart) - without telling more than can be advantageously assimilated and applied, is the device to select and use. The result of this increasingly accepted point of view is that indicating (variables) type gaging equipment is being used far more extensively and is being brought closer to the point of manufacture for machine operator availability and use. This arrangement enables the operator to know and see for himself - the when, where, why, and how much factors of the job he is running; the equipment is to the machine operator exactly what

the chart, compass, and rudder are to the ship's pilot. It enables Management to place responsibility and accountability at the source - exactly where conscientious and capable operators want it to be. Quality Control is essentially (error) preventative; its (error) curative powers should be reserved for emergency use only.

It is hoped that sufficient detail and repetition have been presented to emphasize adequately the importance and complex nature of Screw Threads and related problems in respect to the field of Quality Control, the need for further development and better use of both product gaging devices and gage checking means, and the attendant obligation on the part of both gage manufacturer and user to analyze carefully and correctly their individual problems from the standpoint of contributing to the advancement of the science and entire field of Statistical Quality Control - Today's Foundation for Tomorrow's Reputation (and Security). A more vital compulsion for forthright thought might well originate in the realization of the present chaotic state of international affairs where it is abundantly evident that the usual holding and securing means through diplomacy and the balance of power are inadequate, and that globular areas of like conviction will have to be dependably screwed together to obtain security through this (figurative) technical media, which, we hope, will sustain until more effective, acceptable, amd more enduring means are developed.

QUALITY CONTROL IN TIRE MANUFACTURING.

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Manufacturing processes have become increasingly more complex and involved. Improved designs invariably have tended to reduce manufacturing tolerances; mass production methods have resulted in equipment and processes becoming extremely more complicated; and, in addition, the introduction of other modern methods of factory operation, such as incentive measures, has tended to make the in-factory control problem more and more involved. Along with this has come a clearer understanding that the old-time inspection methods of simply separating acceptable and unacceptable products are no longer adequate to meet industry's need.

Since the introduction of scientific inspection methods, control functions have become much more valuable within the manufacturing organization. The control departments are more efficient in their own operations, more effective in working with other groups and are generally becoming a valuable balancing power between the design and the producing divisions.

In addition, many industries have found increased benefits through more inter-company inspection department contacts. This tends to show that ultimately control groups may be as active in vendor consumer relations as they are within their own factories.

Much of this advancement was not only due to the added use of statistical methods in control work but also to the indirect effect they had in focusing attention on all aspects of inspection. The inspection organizations and their philosophy of operation have received much consideration because industry in general has become more quality conscious.

Considering only the in-factory aspects, the main duties of the modern quality control group appears to be the responsibility for taking the iniative in first achieving and later maintaining control of quality.

In the initial stages of a quality improvement programme when efforts are directed chiefly in getting quality to a satisfactory level, quality control methods have been found in many cases to be virtually indispensable. Without their use it would not be easy to study the relation of one variable to another. Nor would it be possible to measure process capabilities and compare them with specifications to establish realistic tolerances. In fact, before quality control methods were introduced, it is difficult to understand how a logical approach could be made in analysing many of the in-factory problems.

Later, when control of quality has been achieved and inspection is organized on a more permanent basis to maintain this quality level, statistical methods are also useful. Here, probably the simple control chart and the various sampling plans are more widely used. Both tend to give the maximum information for the minimum amount of effort and the psychological effect in posting their results assists in maintaining quality interest on the part of the operators.

In all cases where statistical methods can be used the results are unusually gratifying. However, there are sometimes limitations in their applications, and this is particularly true in the process type of industry. Where characteristics are intangible and their measurement can not be ex-

pressed in terms of numbers then statistics can not be applied. Therefore attention must also be directed towards other methods of inspection. Consequently, in the Dunlop Tire and Rubber Goods Co. Ltd. in Toronto the term quality control is used in the broad sense rather than in the specific use of statistical methods.

This branch of the Dunlop organization produces a wide variety of products. The major volume of materials passes through the Auto and Truck tire department. Other divisions produce auto and truck tubes, bicycle tire and tubes, latex foam cushions, V belts, flat belts, golf balls, hose thread and other mechanical products. Within each department there is a wide variety of sizes and styles. With the exception of the most popular items, production requirements are often scheduled on an intermittent basis. Considering these factors along with our present day conditions of changing materials our quality problems are frequent, varied and extremely complex.

In an effort to produce a high standard product and to reduce in-factory defect losses, the inspection of many of these products was established around the latest quality control thinking. Briefly the control groups were organized to: -

(1) Assess quality levels at all times.

(2) Readily detect any real quality changes in products or processes.

(3) Associate the cause of the trouble with its souce.

(4) Have corrections or adjustments made with a minimum of delay.

When a control group is established in this manner, it becomes the pulse and nerve line of the organization for quality problems. Thus, the early recognition of possible troubles and prompt corrective action goes a long way in not only maintaining efficient control of quality but also facilitates uninterrupted production.

It has been in this manner that improvements, as shown in Fig. 1, have been achieved. In doing so, many of the standard quality control methods have been employed. Charts for variables have been effective in pointing out significant changes in the levels of such items as tire cord elongation, tire balance, tire and component weights and the overall quality index of producing department. The Dodge and Romig sampling plans have been used efficiently in the sundry mechanical products departments. Correlation charts have been used in attempting to ascertain relations between variations in bias angle and the amount of stretch applied in using materials; the changes in elongation of tire cords and changes in local weather conditions; etc.

Rather than describe such applications of these common control techniques, on which much has already been written, the following examples of our work have been selected instead to show the unusual or different approaches.

Example 1.

Material was being lost through excessive overflow or spew during the moulding of a product. There were several existing theories on how the amount of spew could be reduced but there was little in the line of facts. In approaching this problem, the first consideration of the quality control department was to gather data in an attempt to indicate the extent of the variations and where they occurred.

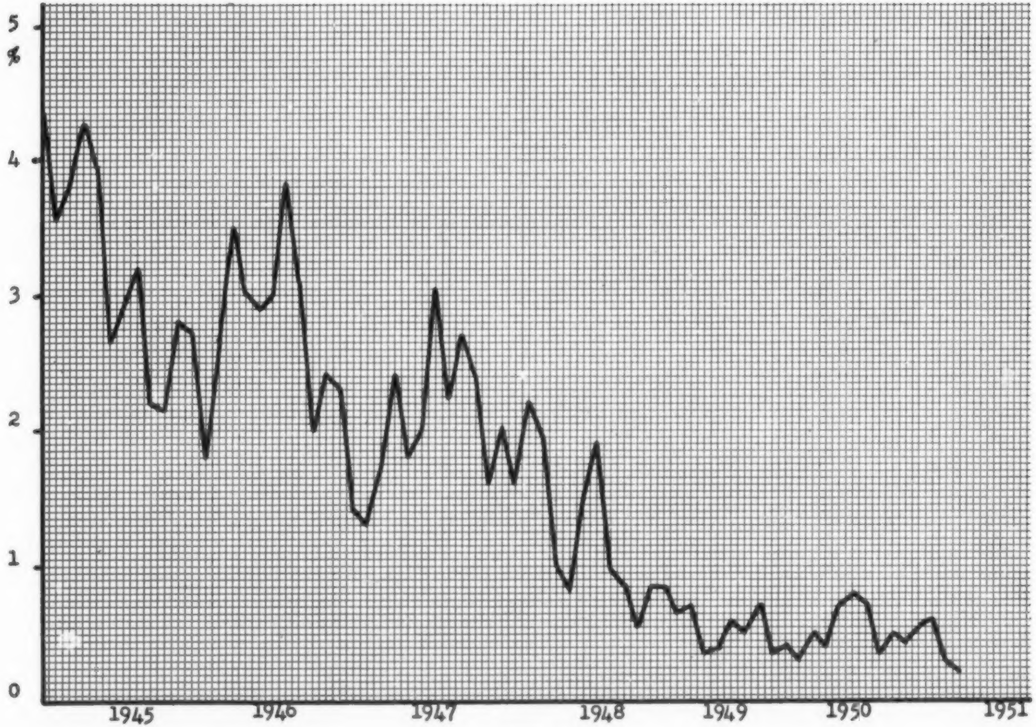


FIG. 1.

To begin with, a number of untrimmed products were selected after curing. These products were weighed with the spew on and the gross weight of each was recorded. The parts were then trimmed and each spew weight was measured and recorded with the corresponding gross weight.

In analysing this data the gross weights were first arranged in the form of a distribution (Fig. 2). This simply indicated we had selected a sample which, because of its uniformity, was likely representative of the overall conditions. In addition, since defects occurred when the gross product weight was somewhere just below the lowest recorded values, it was evident that a saving could be made if the overall variation could be reduced and the average value adjusted accordingly.

The same data was treated further by correlating the gross weight with the corresponding spew weight. In Fig. 3 it can be noted that (1) the amount of trim varies almost directly with variations in the gross weights. Therefore, excessive gross weights cause increased spew losses and do not appreciably affect the net product weights. (2) the two regression lines indicate there is a difference between the volumes of the two moulds. Unless this difference can be reduced the gross product weight must be kept sufficiently heavy to fill the larger mould. This will definitely limit the extent to which a reduction can be made in the overall amount of spew.

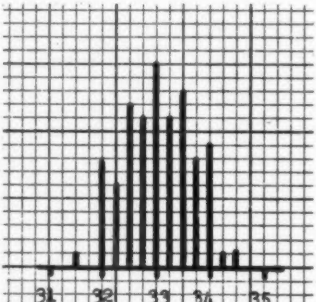


FIG. 2.

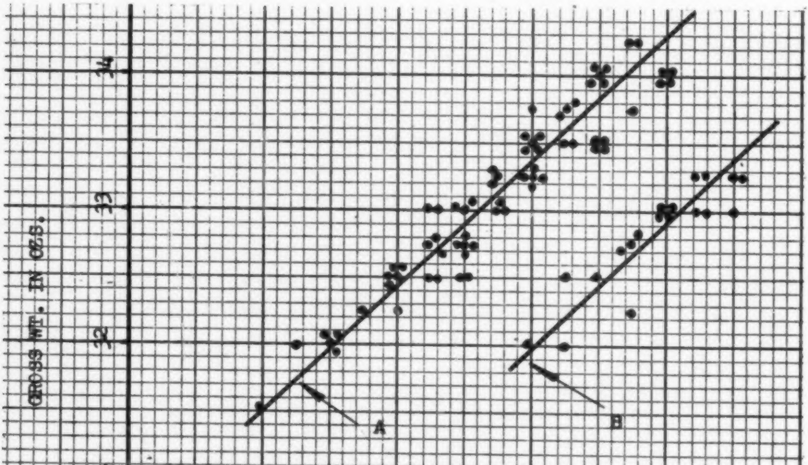


FIG. 3.

Fig. 4 shows the net weight from each mould, and as expected, they are at different levels. It also shows the variability among the net products to be relatively small.

At this stage of the experiment there were still other questions to be answered. What is the minimum gross weight required to fill the moulds without causing defects? What causes the gross weight variation, etc? Since this example was chosen only to indicate how seemingly unimportant information can be used to form fairly conclusive evidence, the other answers must come from experiments and investigations.

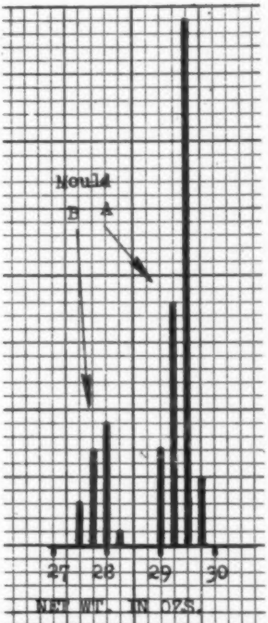


FIG. 4.

Example 2.

When quality characteristics are intangible it will occasionally be necessary to improvise on the standard quality control techniques. An application of this occurs in the measurement of the stickiness or "tack" of uncured rubber and recording it in control chart form.

To begin with the overall range of tack conditions was broken down into three broad categories. Each classification was then defined as follows:

(0-1-2) will not stick to self

(3-4-5) will stick and can be pulled apart with ease

(6-7-8) will stick and can be pulled apart only with difficulty.

With these definitions there was little difficulty on the part of the inspectors in associating actual conditions with one of the general classifications.

This, however, was not sufficiently accurate. Therefore a range of three numbers were allotted to each definition. The definition itself represents the central number in each range. The higher and lower numbers within the range (zero excepted) represent conditions within the general classification, but more or less tacky than the actual definition.

Thus, it was possible for various inspectors throughout the factory to measure and report tack conditions without the results being badly influenced through personal judgment. Fig. 5 shows an actual example.

In performing the test the inspectors were also directed with a few simple rules to minimize variations caused through handling the samples.

The accuracy we received from this method was much greater than we had expected. With few exceptions changes in actual factory tack conditions were reported on our charts. The inspectors, themselves, on checking test samples seldom varied more than ± 1 point. In fact, to-day in this company tack levels are usually referred to in terms of a number.

Further work was also done in proving the relation or lack of relation between the level of tack and the age of the material when the semple was taken.

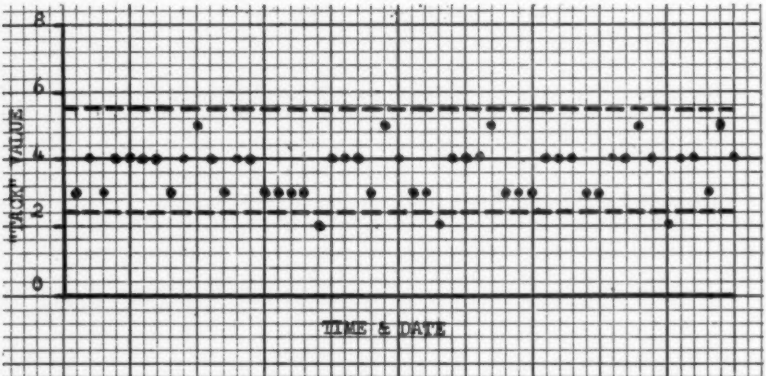


FIG. 5.

Fig. 6 shows a correlation study made by comparing the recorded tack values with the number of days between calendering and testing the sample.

It shows there may be some small relation but since the extremes are within the normal operating limit it is of no practical significance to our methods of operation.

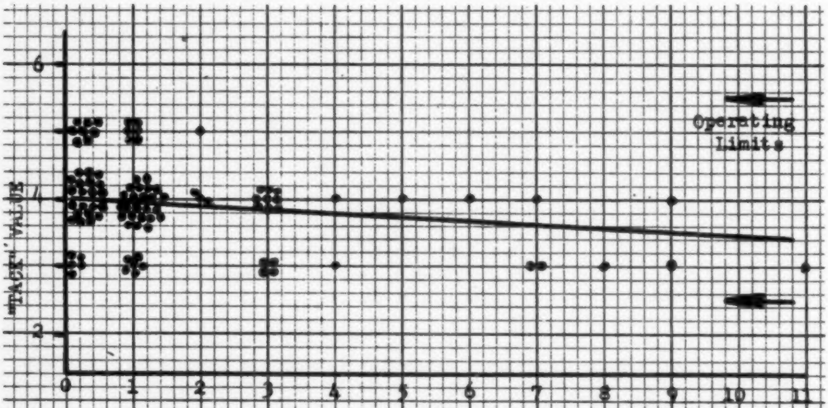


FIG. 6 DAYS BETWEEN CALENDERING AND USE.

Example 3.

On another occasion it was decided to study the various tire manufacturing operations in an effort to learn the cause of a fold defect at the top of the chafer.

No attempt has been made to include the somewhat involved design theory

necessary to complete this discussion. Instead only the control aspects are mentioned, purely to show how a study may be made when direct measurement of the defect are not possible.

The experiment was done by placing evenly spaced threads on the sidewall of the tire and measuring the changes in spaces between them as the tires were processed in the various operations. In all cases the changes were calculated and plotted as percentages of stretch or compression.

After covering all major operations in this manner, only one was found to have any appreciable effect and that was during the period when the tire was in the mould. Figure 7 shows the changes on the surface of the sidewall rubber which occurred during this interval. On plotting this data and comparing it with other component measurements taken from the tire it was found that -

1. The defect occurred in the centre of the area of maximum compression.

2. The chafer ended in the same location.

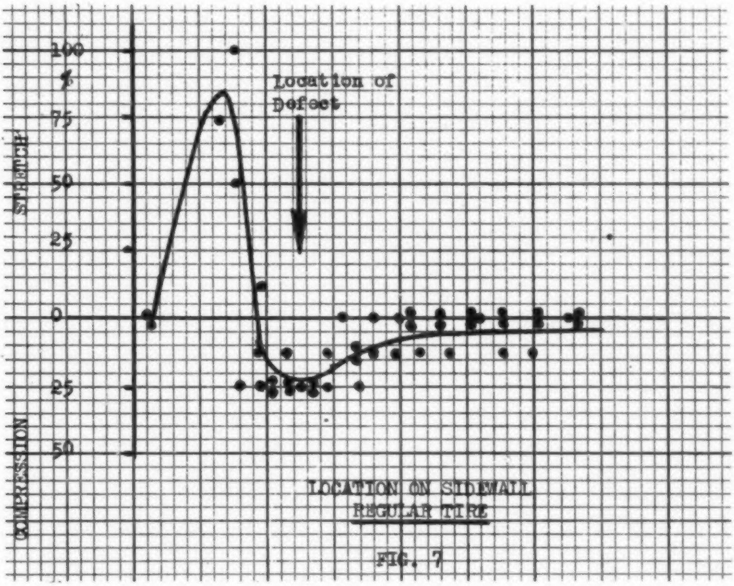
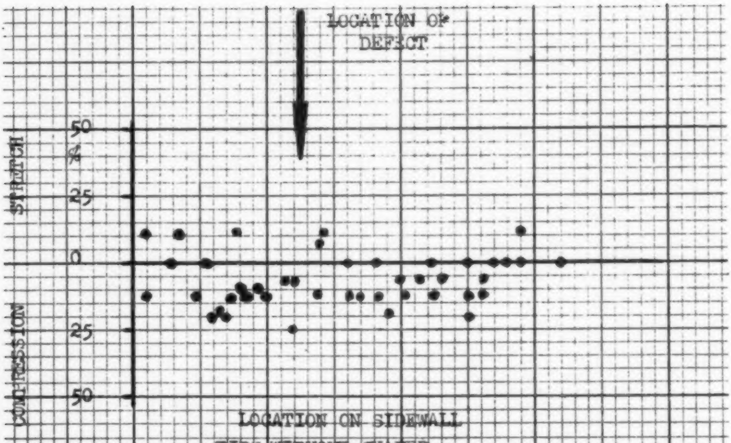


FIG. 7

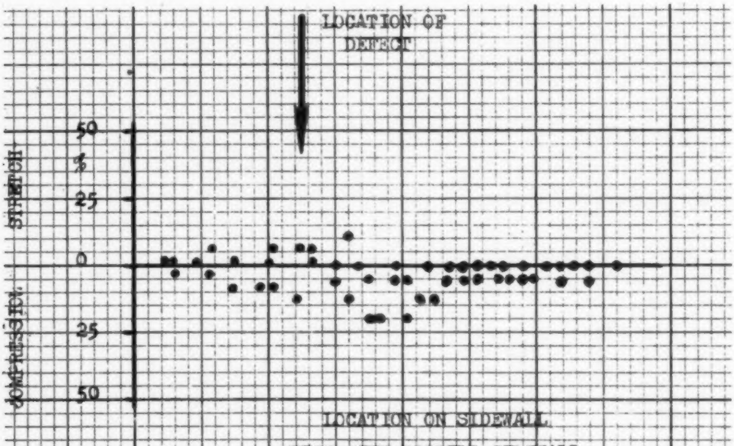
Further experiments were then conducted in the same manner by building a tire without a chafer. Figure 8 shows the results. It will be noted that we did not have the same extreme stretches and compressions as shown and no defect occurred, as in Figure 7.



TIRE WITHOUT CHAFER

FIG. 8.

A similar result was also achieved and shown in Figure 9. The sidewall was profiled in an effort to prevent material flowing into the area of compression and stop the fold from occurring.



TIRE WITH PROFILE SIDEWALL

FIG. 9.

THE QUALITY EVALUATION POLICY OF THE AIR MATERIEL COMMAND

Brigadier General Walter G. Bain, USAF
Quality Control Division, Air Materiel Command

The title of this panel discussion, "What the Armed Services Expect of the Contractors' Quality Control Department", defines quite clearly the objectives and scope of this paper. I shall try to fulfill the promise implicit in that title and sketch for you, in as much detail as possible, exactly what the Air Materiel Command expects Quality Control-wise from suppliers under contract to the Air Force. The first problem in a paper such as this is one of semantics; it is a particularly perplexing problem in Quality Control because such terms as "Quality Control", "Statistical Quality Control", "Inspection", and "Sampling Inspection" are frequently bandied about without any firm understanding as to what these words really mean. For example, I notice that the circular announcing this convention speaks of "Industry's Quality Control and Inspection Departments" with the implication that the terms "Quality Control" and "Inspection" refer to two distinct and different functions of industrial management. Organizationally that may be true in industry, but in the Air Force it is not true.

For the purpose of this discussion, I should like to define what the term Quality Control means to the Air Materiel Command.

> Quality Control is the sum of all those interrelated activities by which quality is accurately and economically evaluated and controlled.

You will note that by this definition Quality Control includes (1) evaluation, which is more or less a synonym for inspection as that word is conventionally understood in industry, and (2) control, in the statistical sense—the determination of when a process is or is not operating under a system of chance causes. Incidentally, Deming makes a similar distinction when he speaks of enumerative and analytic methods of statistics. By the former we simply estimate quality and by the latter we probe for the causes which influence quality. The problem of evaluating the quality of material actually presented for acceptance is enumerative; the problem of determining why machines do produce material of a given quality is analytic. Quality Control in the Air Materiel Command is largely a quality evaluation or enumerative function.

I am stressing the importance of a clear definition of Quality Control not for the purposes of being pedantic but rather to bring into focus that area of Quality Control which is of primary concern to the Air Materiel Command--quality evaluation. Our job is to determine whether or not supplies conform to established quality standards. Of course, we are interested in control but that interest is secondary to our primary responsibility of evaluation. As I will indicate later in this paper, the Air Materiel Command encourages contractors to use established process control methods. But our job is not to promote or to "sell" the use of statistical procedures except as one variety of useful techniques among others.

Now let's get down to business and find out what the Air Materiel Command expects in Quality Control from the contractors. I have the choice here of itemizing all the numerous details of requirements for controls (using that word in the non-statistical or mechanical sense) of gages, materials, drawings, and myriads of other items, or of presenting to you a statement and an analysis of the guiding policy of the Quality Control Division of the Air Materiel Command. I choose the latter alternative because, I am sure, that with a knowledge of the Air Materiel Command's thinking and point of view on quality control you can obtain a deeper and more beneficial insight into how to do business with the Air Force than if I discussed the numerous procedures and directives which implement that policy. Briefly, our policy is this: We will accept material on the basis of reliable, objective quality evidence. We are not particularly worried about the source of that evidence. We can get it ourselves or from the contractors. In any event, acceptance must be based on evidence. But we want to gather this evidence with a minimum duplication of effort of Government inspectors and contractors.

More formally, let me read the policy given in Directorate Office Instruction 74-1 of the Directorate of Procurement and Industrial Planning of the Air Materiel Command.

AIR FORCE QUALITY CONTROL POLICY

> "CONFORMANCE. Conformance to contractual requirements of supplies presented to the Air Force shall be determined on the basis of objective quality evidence. Such evidence will be obtained by the contractor and will be evaluated and verified by the Air Force Quality Control Representative exercising surveillance over the contractor's facility. Evidence may also be obtained independently by Air Force Quality Control personnel.
>
> PRODUCT INSPECTION. Product inspection by Air Force Quality Control personnel will be used to the extent necessary to verify evidence of quality submitted by the contractor or it may be used to determine acceptability of supplies on an individual or lot basis. The amount of evidence obtained or verified through product inspection by Air Force Quality Control personnel will depend upon the nature and intended use of the product and the effectiveness of the contractor's control over quality."

At the risk of laboring the obvious, I may add that the Air Force expects each contractor to have an effective Quality Control organization which is responsible for providing evidence to substantiate the purported good quality of the contractor's product. The degree to which such evidence is available will determine the extent of Air Force surveillance. This policy thus provides clear-cut incentives for contractors to go all out for Quality Control. As we visualize this policy in operation,

it covers the range from certificate acceptance all the way to 100% inspection by Air Force personnel depending on the contractor's cooperation and product quality. Our fixed and unwavering objective is to provide the Air Force with maximum protection against the acceptance of substandard material at minimum over-all cost. I emphasize "minimum over-all costs" because we are concerned with the final bill the taxpayer has to pay regardless of whether money is expended in the form of Government or contractors' checks.

Now let me very briefly paraphrase and summarize the Air Materiel Command's Quality Control policy.

1. Material must conform to specification requirements.

2. Conformance is determined by evidence.

   (a) Evidence provided by contractor.
   (b) Evidence obtained by Air Force.

3. Evidence obtained by Air Force is minimized when:

   (a) Through a process of verification and evaluation, a contractor's Quality Control system and practices are found to be acceptable.

   (b) Quality is satisfactory.

The key word of this paper is "evidence". The Air Force says, in effect, that contractors who provide evidence (1) that their Quality Control systems are effective and (2) that their products conform to established quality standards can expect the most expeditious acceptance of their product. I think that this subject of evidence deserves further treatment. Parenthetically, I should like to remind you that when I speak of the contractor's Quality Control system, I use the words "Quality Control" in their most generic sense—all those activities that relate to evaluation and control.

The first evidence that a contractor must give the Air Force is information regarding his Quality Control system. One of the basic articles of a standard Air Force contract provides that contractors shall establish an acceptable and complete system covering Quality Control of all material, fabrication methods, and finished parts. The system must be approved by the Government representative who is assigned to the contractor's plant. This provision forms the basis for much of the Air Force's policy on Quality Control. Since it is uneconomical for the Air Force to maintain a staff of operating inspectors to perform all of the Quality Control functions, the contractor must provide the basic inspection and is paid to perform this operation. The Air Force admits that the contractors' physical inspection is a substitute for Air Force physical inspection—if the contractor has an acceptable Quality Control system. The Air Force buys a quality control service as well as a physical article from the contractor. What constitutes in detail an acceptable quality system is beyond the scope of this paper. In passing I might say, however, that the Air Force does not demand more than what good management ordinarily provides—regardless of whether or not the Air Force is on the premises.

The second type of evidence relates to the product itself. Considering that we are concerned with the evaluation of everything from thumbtacks to B-36's, I can only indicate in broadest terms what quality evidence we expect from contractors. And at the outset, of course, I am assuming that 100% inspection in the most literal meaning of that term (evaluation of all characteristics of all items) is practically prohibitive for economic and other reasons. Then what evidence of product quality do we want? In outline form let me try to indicate what the Air Force expects.

1. Evidence that inspection testing and control is planned with respect to:

    a. Characteristics evaluated or controlled.
    b. Risks of error.

2. Evidence that the plan was executed (quality records).

3. Evidence that proper action was taken.

The Air Materiel Command, in effect, says this: Planning for evaluation of quality with respect to specifications and drawings involves judgements of two kinds--(1) engineering; (2) statistical. This is true because the extent of evaluation by physical testing, by dimensional inspection or visual examination has practical limitations. Therefore, evaluation must be planned to focus attention on those characteristics of greatest engineering significance, and such evaluation must be associated with a calculated risk of error. The Air Materiel Command wants to know specifically what characteristics are evaluated and the specific sampling procedures, if any, used for such evaluation. The effect of this requirement is that contractors' decisions regarding evaluation practices must be made at a high level. Such evaluation must be planned to achieve broad and carefully coordinated over-all control so that inspection activities in all areas of a production facility are integrated to effect economy of operation and communication.

Engineering planning may be reflected in the form of a Classification of Defects which is simply an orderly grouping of characteristics into categories of different degrees of importance--critical, major, and minor. But whether or not a formal classification is necessary for a particular item, engineering decisions must be made in advance as to what characteristics are to be tested or inspected. Such decisions are too important to be shifted to lower level Quality Control personnel. I should like to stress that this systematic analysis of quality characteristics in the form of a Classification of Defects yields substantial benefits to contractors in all the areas of operation--in design and production as well as in Quality Control. The subject of Classifications of Defects has not received the attention it deserves in Quality Control literature, but it should be quite obvious that intelligent quality evaluation requires first a careful analysis, a picking and choosing, if you please, of what characteristics should receive prior or more rigorous scrutiny in inspection. This engineering judgment must be complemented by careful statistical planning. This is true regardless of whether or not inspection is by attributes, by variables,

or by some chart control method. Decisions must be made in advance regarding the risks which may be intelligently taken in evaluation. This problem of risk is too broad to discuss here. All I need say is that the day of blind sampling is past. We may not always like the risks associated with a particular sampling plan but at least we should know what those risks are. Evaluation procedures such as I have been outlining, based as they are on engineering and statistical forethought, serve the interests of both the Government and industry. By such methods it is possible to replace subjective procedures by practices which are amenable to some degree of verification. By achieving objectivity in evaluation, industry also obtains numerous valuable by-products of a non-statistical character, not the least of which is a reexamination of tolerances.

As a brief digression, I should like to touch lightly on two topics which I know interest many contractors. The first has to do with how soon and to what extent contractors must make objective evidence available to the Air Force. The second has to do with statistical process control. I think that I can dismiss both of these topics rather summarily. First, in Quality Control as in all other fields, the old saw about Rome not being built in a day is true. We do not expect contractors to provide completely satisfactory quality evidence overnight. We do expect, however, that contractors will have competent and effective Quality Control organizations for the purpose of planning evaluation procedures and generally making a start in the right direction. The Air Materiel Command is willing to cooperate with manufacturers who realistically face their quality control problems and attempt to solve them. Secondly, regarding statistical process control. The Air Materiel Command leaves it to the option of contractors whether or not to use statistical methods of process control. Ordinarily, however, provident contractors will make use of all techniques which reduce cost and improve efficiency. The Air Materiel Command is willing to accept process control data, under specified conditions, as evidence of satisfactory quality. I mention this here to preclude any possibility of misunderstanding about the Air Materiel Command's attitude on any aspect of Quality Control.

The proper understanding and appreciation of the Air Materiel Command's policy requires some background information regarding the circumstances under which this policy has been evolved. Let me mention just two pertinent considerations. First, as with all Government agencies, the Air Force must be prepared to give an accounting of its stewardship to all the people. Secondly, as a consumer, the Air Force is not in the same position as private industry or as a private individual. The Air Force buys supplies, but the people from whom these supplies are purchased are also the people who, together with their neighbors, support the Air Force. In this connection we have, then, two responsibilities: (1) to assure the public that the equipment purchased by the Air Force is of highest quality (such assurance is strongest when supported by proof from both operational and manufacturing sources), and (2) to assure the public that all persons selling to the Air Force are treated equitably. Contractors, for example, have a right to expect that quality evaluation procedures will be as uniform and as impartial as possible, and that competitors will not be treated preferentially because of the vagaries of inspection practices. (Incidentally, the

peculiar position of the Air Force as a consumer purchasing from taxpayers explains in part why our sampling procedures so frequently index quality with reference to producer's risk rather than consumer's risk. We are concerned with the equitable treatment of producers.

As a further complicating consideration, it is well to remember that a military organization like the Air Force is not in a position to accept consumer reaction as a check-rein on quality. I mention this only because it is often difficult to convince new contractors of the necessity of tempering their Quality Control outlook to the exigencies of military procurements. In a strictly civilian environment, competition and consumer reaction militate against poor quality. Two factors make these instruments ineffective in a military environment: (1) In order to perform a military mission the risks of detecting unsatisfactory quality in the field must be minimized; and (2) because of complex communication problems, the military can not depend on prompt and complete information on the defectiveness of supplies delivered to the field, unless, of course, that defectiveness is particularly glaring or serious. This is especially true with respect to evaluating and reporting on such elusive quality characteristics as durability and life.

These thoughts on public responsibility in Quality Control merely suggest some of the factors which influence the orientation of the Air Materiel Command's Quality Control policies. Highly systematic and analytical methods of control and evaluation spotlight the gravity of this responsibility. Quality is no longer some nebulous concept enshrouded in vague and purely qualitative language and, as a result, we are rapidly developing techniques which permit us to translate our concepts of quality into quantitative terminology which is applicable to meticulously defined quality characteristics. Responsibility for quality can no longer be compromised by confused language. In the Air Materiel Command we recognize that the degree to which we realistically accept our responsibilities in matters of quality is reflected in the efficacy of our quality control procedures. Results are subject to some degree of quantitative appraisal.

It has been very pleasant for me to have had this opportunity to discuss Quality Control policy with you. I want you to know that the Air Materiel Command is wide awake to the challenge of Quality Control and is continuously studying both its theoretical and practical aspects to determine how it can best be utilized to serve the Air Force. We realize that Quality Control has not as yet been exploited to the fullest. In Quality Control, as in all scientific progress, practical men must take new ideas and translate them into action by applying them to the solution of problems faced every day in design, engineering, testing, inspection, and production. As Chief of the Quality Control Division, I have, you might say, a selfish interest in Quality Control in behalf of better equipment for the Air Force. But I assure you that your personal interest and cooperation in applying and developing better Quality Control methods will not only serve your country in this time of industrial mobilization but will also be richly rewarding to all of you who want to infuse new ideas into your everyday work, and push forward still further the frontiers of industrial efficiency.

PREPARATION AND USE OF AREA CURVE IN PRESENTING INFORMATION

L. K. Vollenweider
John Deere Waterloo Tractor Works

As a member of an industrial inspection department, I would like to look at Quality Control from an inspection angle. From the literature that is available on "Statistical Quality Control", it is apparent that this system of analysis is so flexible that it can be adopted to almost every occasion or requirement.

Quality Specifications are set with both the producer and the customer in mind. The cost plus the quality requirement determine the limit set on the dimensions on the part. Some method of determining the conformance of the parts to the specifications must be adopted.

At the John Deere Waterloo Tractor Works our method of inspection prior to 1945 was "final inspection". That is, the operations assigned to a department were run, and then the material was delivered to an outgoing area where inspection was performed.

Our contact with "Statistical Quality Control" has been since 1944 and our problems have been, perhaps, the same as everyone who comes in contact with statistics for the first time. To adopt "Statistical Quality Control" it is necessary that some one in the organization should understand the ideas back of the various theories. The one responsible for the program must be able to answer the basic questions and opposition that he will encounter.

I was assigned that responsibility and since this was my first contact with statistics, I had to start by trying to educate myself so that I could understand the rules that had to be followed and some of the theory that makes Quality Control work.

The theory that fascinated me the most, and in which I had the least faith was the theory of the Normal Curve, as applied to shop dimensions. To find out how dimensions did behave we actually proved this theory by inspecting sub-groups 100%. It was surprising how shop dimensions follow the Normal Curve. Our general findings on screw machine parts, grinding, precision boring, etc., were that these operations follow the Normal Curve as good, or better than statisticians and mathematicians tell us.

Our finding sold us on Quality Control. Our method of research was to sample and 100% inspect, analyze the samples by 3 sigma control limits and if "in control" compare the prediction of individuals with the 100% inspected pieces.

Figure "I" shows our method of comparison. This study is on a stud (CX 85409 A) and the pitch diameter is analyzed. Plotted are averages of (5) samples out of each (50) produced. The process is "in control" on averages and range. The predicted spread of individuals is at +18. ($U.C.L._x$) and - 13.5 ($L.C.L._x$).

This chart is made using coded values of .0001, which means that the +18 is actually +.0018 and the -13.5 is -.00135, all taken from the mean of specification, which is represented on the chart as 0.0.

To the right of the Average Chart is shown the frequency distribution of the pieces in the sample and to the extreme right of the chart is the frequency distribution of all the pieces produced in this run, or 986 pieces.

Generally there is a difference in the spread of the sample and the predicted spread, which is one point that many people starting to use Statistical Quality Control lose sight of, but when we analyze a process, using the 3 sigma control limits, we expect to find about three pieces out of a thousand that are beyond our prediction, as indicated in this case history when a 100% inspection was made.

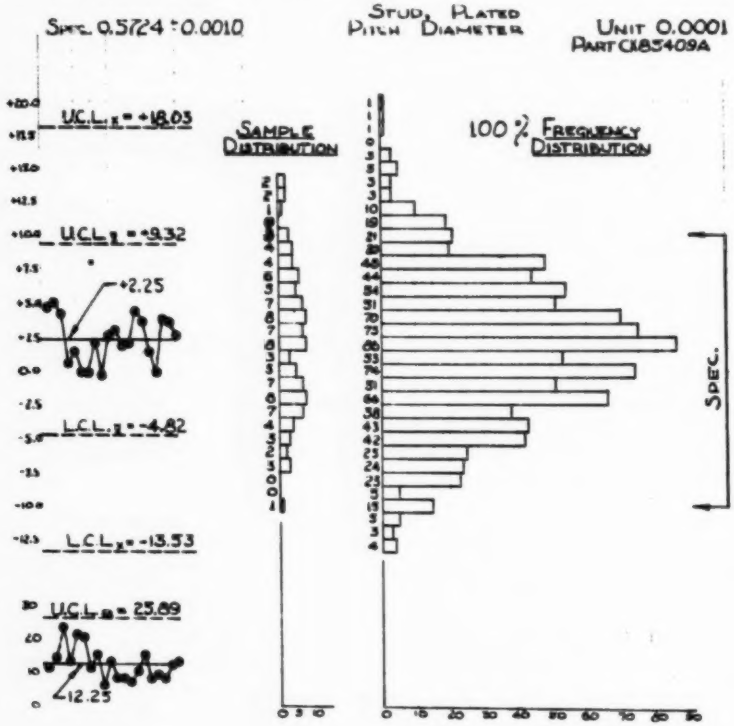


FIG. I

OUR INTRODUCTION TO CALCULATIONS OF NORMAL CURVE

Early in our Quality Control program we received an issued of "INDUSTRIAL QUALITY CONTROL", in which there was an article by Mr. M. A. Brumbaugh which explained the use of the Table, "Areas of the Normal Curve" in estimating the per cent of scrap and reclaim.

Formula to find number of sigma from process average to the upper and lower tolerances of specification.

$\frac{U.B.P. - \bar{\bar{X}}}{\text{Sigma}}$ = number of sigma from average of process to upper blueprint.

$\frac{\bar{\bar{X}} - L.B.P.}{\text{Sigma}}$ = number of sigma from average of process to lower blueprint.

U.B.P. = upper limit of specification
L.B.P. = lower limit of specification
$\bar{\bar{X}}$ = average of process

The values given by these two formulas are found in the Table, "Areas of a Normal Curve", which gives the per cent of the area under the normal curve for that number of sigma on either side of the process average. That value is subtracted from 50%, and the difference is the per cent outside specification on that side of the average.

This was a very important addition to the tools of analysis at our disposal. At first we used this information in reporting on quality within our shop. The next use of this method was in reporting on engineering investigations. We found that those not familiar with Quality Control would accept our findings more readily if we included these estimates. Finally, we included this information in reporting on shipments of purchased goods that did not meet our accepted standards.

Figure "II" shows our standard method of presenting information which is outlined as follows:

A. Obtain random samples for all shipments or lots.
B. Construct an average and range chart.
C. Record frequency distribution of samples.
D. Make a normal curve and calculate per cent of area outside specification.

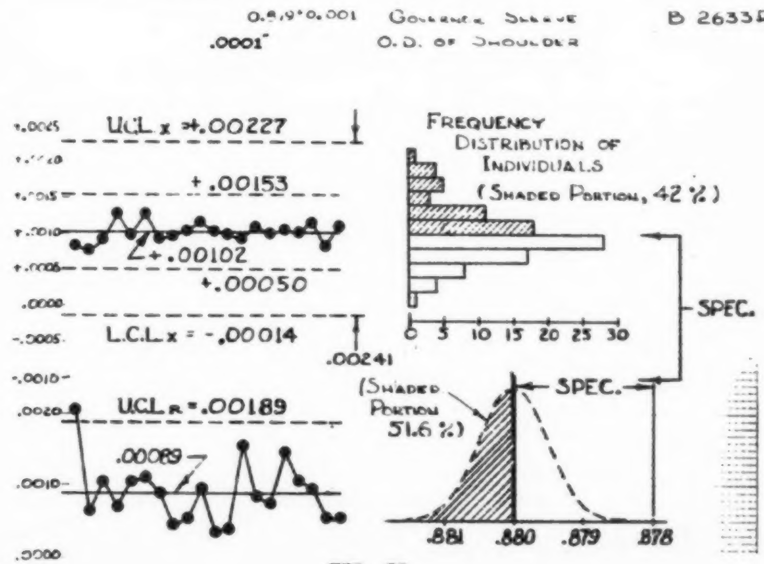


FIG. II

Figure "II" is a case history of the outside diameter specified to be .879 ± .001. The average and range chart is for twenty averages and ranges based on five samples each from twenty different boxes in one shipment.

The chart shows in control on averages with one plotting out of control on range. To the right of the averages plottings is a frequency distribution of the samples which, by count, shows 42% outside specification. However, in using the prediction of the spread of individuals, according to the normal curve at bottom right side of the chart, we would expect to find about 51.6% of the parts in the shipment outside specification.

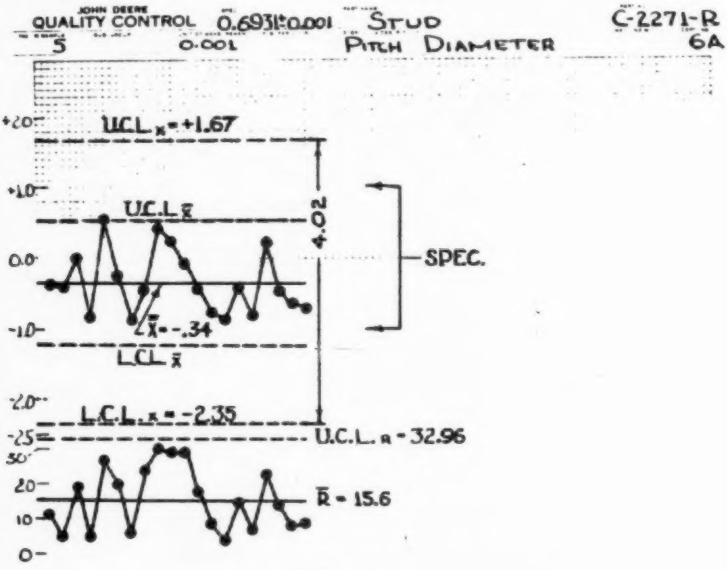


FIG. III

NECESSITY OF INCLUDING FREQUENCY DISTRIBUTION

Figure "III", which is a control chart of pitch diameter of a stud, reveals an in-control process with prediction of the spread of individual pieces in the shipment to exceed both the upper and lower specification.

The study was made because of a reject having been written by our Receiving Department on a shipment of studs which had been sampled by attribute in accordance with the J.A.N. Tables, and in order to show how much variation could be expected, the chart of twenty samples of five each was made, and since only over-size studs were found in the samples, there was no mention made of under-size studs being present in the shipment. An analysis of the data represented in this chart indicated a considerable number of studs were under-size.

Figure "IV" shows the same chart of averages and range, to which

has been added a frequency distribution of the samples, and it will be noted that 34 pieces are at -1.0, with none smaller. This indicates that a sorting operation had evidently been performed on this lot before it was shipped, and further points out the advantages of a frequency distribution of samples before making a final decision.

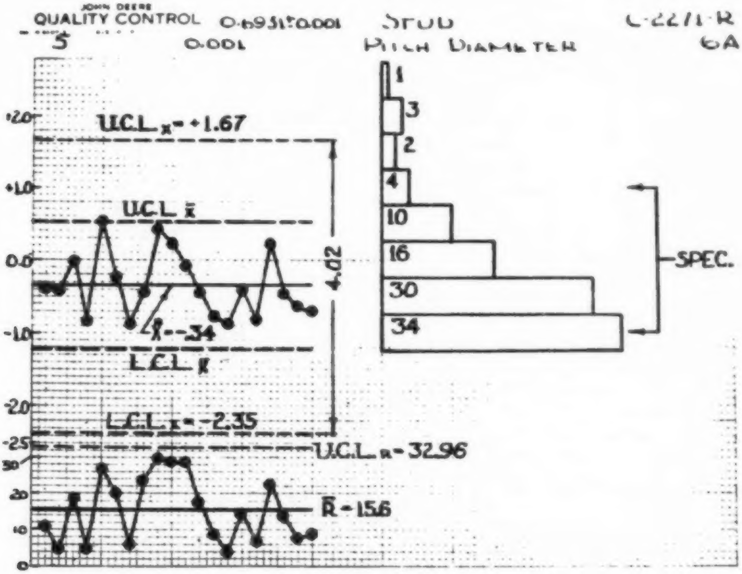


FIG. IV

OUT-OF-CONTROL CHARTS

As an aid in explaining out-of-control charts, we apply the frequency distribution of the samples, as shown in Figure "V", which is a study of a process made by taking four pieces out of each 25 produced and making an average and range chart.

An analysis of this chart reveals three (3) plottings of averages and one (1) of range that exceed the three sigma control limits.

When using Quality Control analysis, we are told that we cannot depend on predictions that are made on an out-of-control process, as there will generally be more variation than predicted. Therefore, we believe that with the prediction of variation which we get in an out-of-control process we should also use the frequency distribution of the samples, as it will point out more clearly that difference.

It is noted in Figure "V" that there were two (2) pieces out of the 80 that are definitely smaller than the prediction.

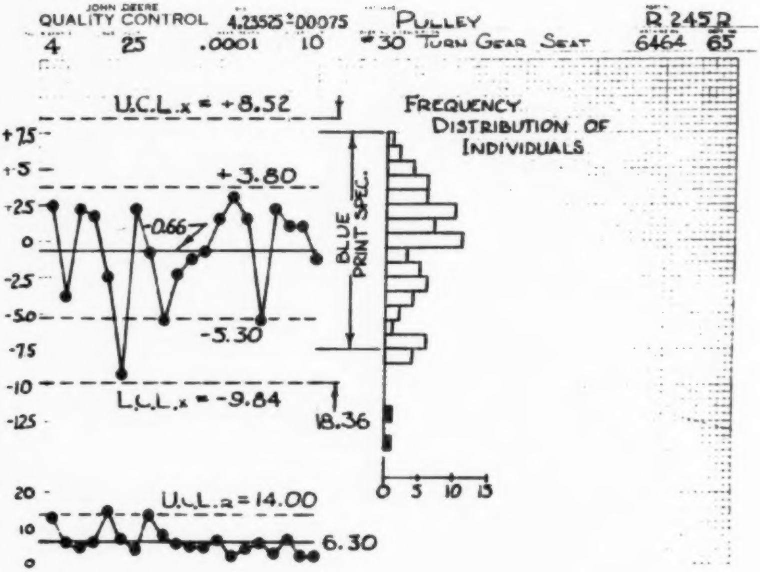


FIG. V

In conclusion, our findings have been that the Shewhart Control Chart as used in the Metal Producing and Fabricating Industries as applied to machine dimension is reliable and efficient. Frequency distribution of samples should be applied as additional analysis and should be used in presenting information to the Design Engineer, Methods Engineer, or a vendor.

THE USE OF STATISTICAL TECHNIQUES FOR INVESTIGATIONAL PURPOSES

Carl V. Garrett
Allison Division, General Motors Corporation

This subject, "The Use of Statistical Techniques for Investigational Purposes" was chosen because it has been of great value to us at the Allison Division of General Motors, Indianapolis, Indiana. It is my feeling this technique is of particular value to Industry now even more than in normal times. So many companies are starting defense programs; starting to produce items that are new and strange; items with which they have had no previous experience, and to some degree their regularly established statistical quality control techniques will be retarded. For this beginning period mistakes are sure to be made and products will not meet model test efficiencies or expectations. I am sure statistical quality control techniques for investigational purposes will be helpful. With this thought in mind, members of my staff have prepared (7) examples of actual cases in our plant where these techniques have been applied in investigations.

Before I give you these (7) examples, I would like to clarify the nature of our business. I am sure the name "Allison" brings to your mind airplane engines - jet engines. That is true. We do produce jet engines; as a matter of fact, we are the largest producer of jet engines in the United States. One of our plants, all under one roof covering approximately (50) acres, is owned by the United States Government. We also have approximately 350,000 square feet of floor space devoted to aircraft engineering and flight test operations. In addition to our aircraft activities, we have approximately 1,855,000 square feet of floor space devoted to producing numerous parts for Diesel Locomotives for Electro-Motive Division, silver bearings for various engines and both Commercial and Ordnance transmissions of the torque converter type. So, we have drawn from our experiences in different plants in preparing the (7) examples. The subject of our first example is: "Gaging Unit #1 vs. Gaging Unit #2".

In most all products that are produced, the Inspection or Quality Control Department usually finds one or more of the detail parts are quite difficult to gage. On the Jet Aircraft Engine, we can find several parts that fall in that category, probably one of the most difficult being the airfoil section of our Turbine Buckets.

The first two or three years we were engaged in the manufacture of the Jet Engine, we designed, devised, and built or purchased several different types of gaging equipment. Sooner or later, each piece of equipment was abandoned as impractical or unsatisfactory.

About two and one-half years ago, we purchased some equipment which appeared to satisfy our needs. (Just for talking purposes, we will call it Gaging Unit #1.)

There was no doubt about it; after we started using Unit #1 we were able to obtain more accuracy and consistancy in measurements and at a faster rate than had been possible with any of the previous equipment.

The inspection of the airfoil section, using Unit #1, was accomplished in two operations. The dovetail section of the Turbine Bucket was located in a nest and with mechanical followers, produced an exact image of a given airfoil section on an emulsion coated glass. The image transposed was then projected, usually to ten times actual size, against a large screen simultaneously with a master reticle of the same airfoil section. After proper alignment or location was made, the actual measurements were then obtained.

However, there were certain people in our Engineering Department who still were not satisfied with our method of inspection. Consequently, they decided to design a gaging unit which they felt would do the job properly. (We can call this Gaging Unit #2.) The inspection with Unit #2 was also accomplished in two operations. The dovetail was located in a nest and through mechanical and electrical means, a ten or twenty times size transcription of a specified airfoil section was made on paper. A large master was then superimposed on the transcription and after proper alignment, all measurements were obtained by reading a scale on the master chart.

The development of Unit #2 caused a considerable amount of controversy and as time went on the use of both units only served to "fan the flames higher". Parties soon aligned themselves with one faction or the other and the arguments and discussions grew more heated each day.

It was evident that something had to be done because both sides claimed to have a superior unit insofar as accuracy of measurement was concerned. We assigned two of our Statistical Quality Control men to tackle this job in order to determine how they compared with each other.

The first step was to become thoroughly familiar with the operations of both units. Next, they set out to determine what inherent variability in accuracy was prevalent in both units. To accomplish this, one Turbine Bucket was chosen at random to be used for all tests.

During the next week, the "A", "B", "C", and "D" dimensions of the Turbine Bucket airfoil section were measured twenty different times and the values recorded. The measurements were taken after establishing the best fitting contour between the projected image and master reticle. Assuming the first measurement to be correct for each dimension, we established it as zero and adjusted all other readings to it and recorded them as units of error. From these values, we calculated the average error and curves illustrating the expected spread of error as shown in figure No. 1.

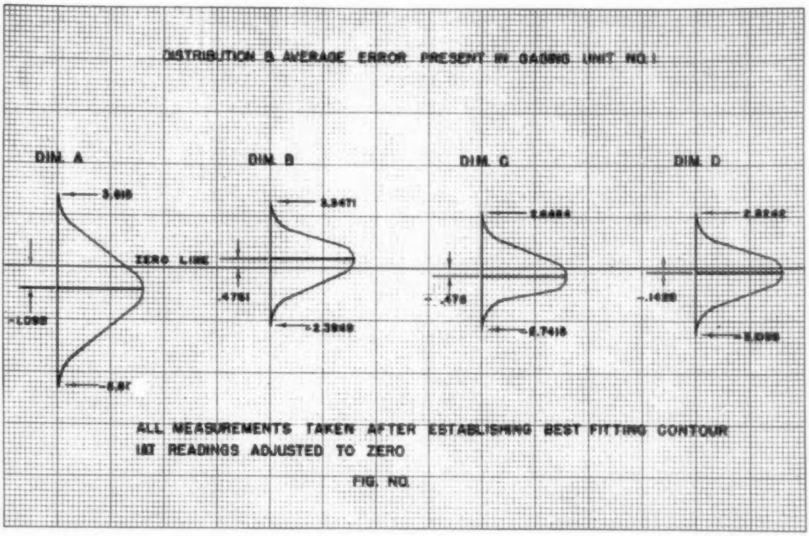


FIGURE NO. 1

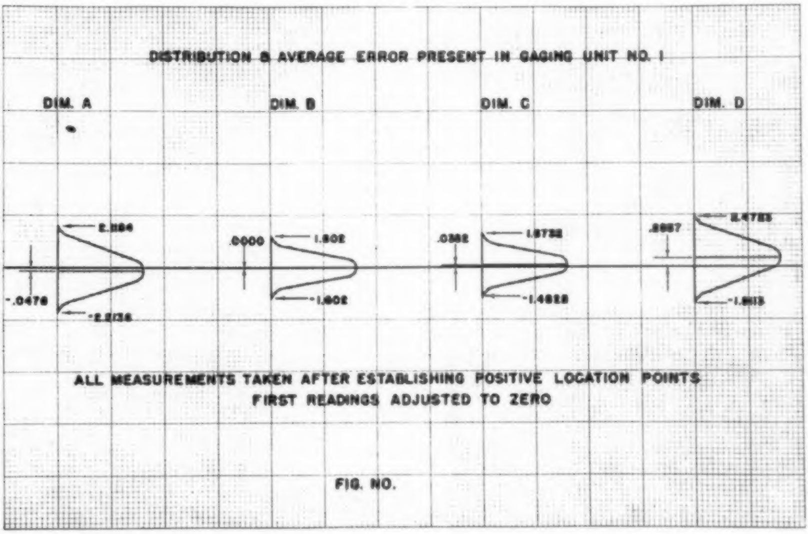


FIGURE NO. 2

The twenty slides from the first test had been saved so we ran each of them through the projector for the second time and again recorded the values for each of the four dimensions. However, this time, we established positive locating points and took the measurements. We repeated the same process that had been followed when the measurements had been taken from the best fitting contour, and determined the average error and expected spread of error as shown in figure No. 2.

It was readily noticeable that the amount of error reduced considerably if the image was measured from positive locations rather than the best fitting contour. Figure No. 3 shows the comparison of the two. That finished the test for Gaging Unit #1.

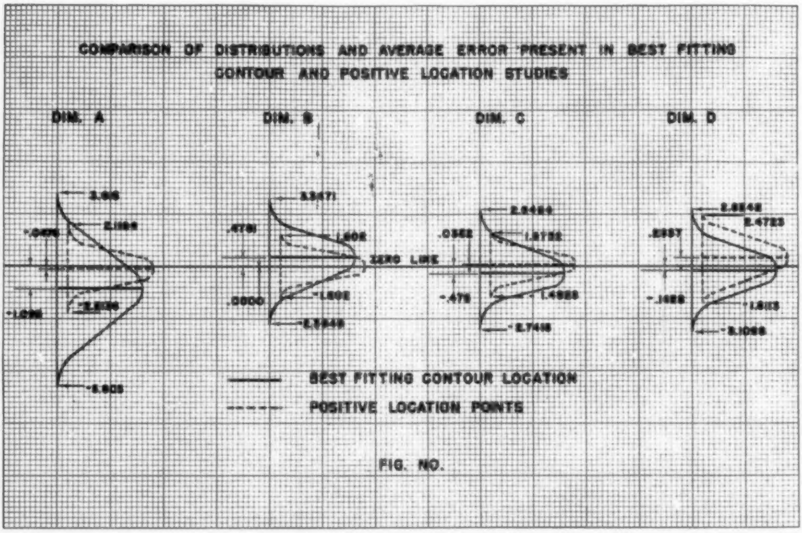


FIGURE NO. 3

The same Turbine Bucket was used for testing Gaging Unit #2. A transcription and inspection of the same four dimensions was made twenty different times during the next few days. We used the same method to calculate the average error and spread of error as had been used with Gaging Unit #1. Because it was their normal practice to always obtain measurements from positive locating points, we only conducted the one test. The calculated prediction of error for each dimension is shown in figure No. 4.

We made a comparison of the prediction calculated for each Gaging Unit and were quite amazed. The average error and spread of error was practically the same. This comparison is shown in figure No. 5.

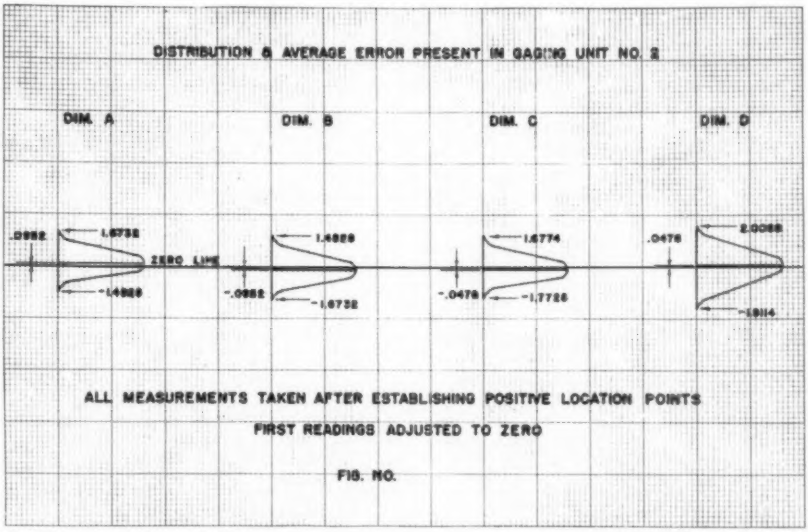


FIGURE NO. 4

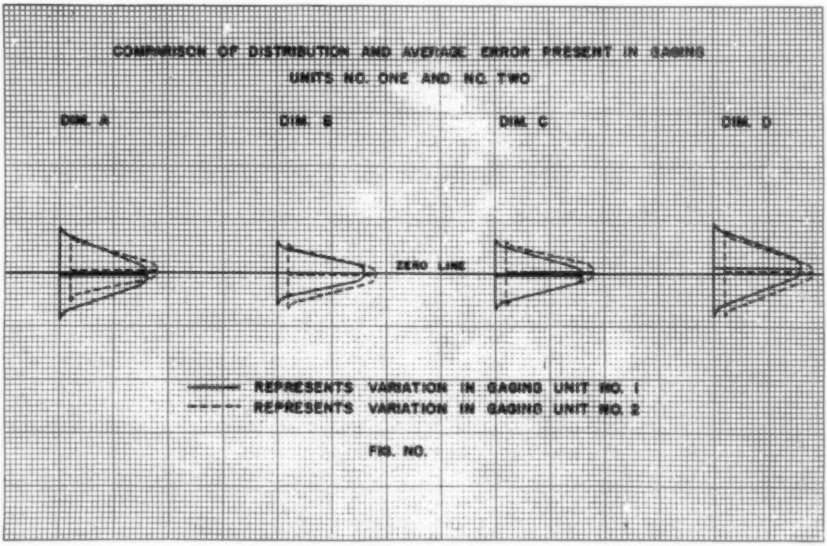


FIGURE NO. 5

Almost immediately after the tests had been completed and the facts became known, there was a definite change in attitude and the heated discussion stopped. The most conscientious believers in both Gaging Units began to discuss their merits and make suggestions for improvement.

TURBINE BUCKET INVESTIGATION

Quite often the need for investigation is overlooked when making a study. We are sometimes living in a fool's paradise and are not aware of it.

This study was made when we first got into Statistical Quality Control and our knowledge was more than somewhat limited. We were checking Turbine Bucket contour thickness with an indicator type gage and recording this information on $\bar{X}$ & R charts.

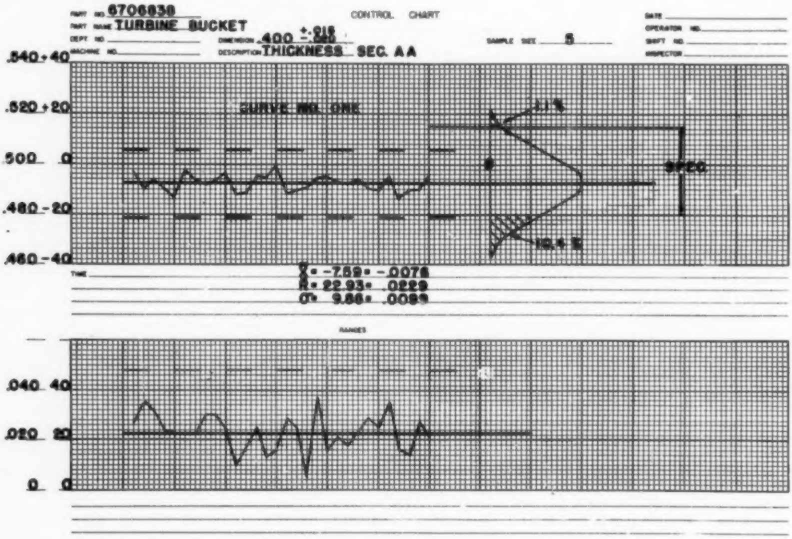


FIGURE NO. 6

The first glance at figure No. 6 shows a process that is in an excellent state of control but producing pieces out of specification on both sides. However, the more we looked at this particular chart the more we realized that something was not according to "Hoyle". We hadn't heard of stratified data, or too much about probability of occurance. In spite of all our innocence we did know that the control limits for averages meant that we could expect average points to extend to both control limits. Since all average points confined themselves to approximately 1-1/2 sigmas on either side of $\bar{\bar{x}}$ it more or less confirmed our suspicions that something was amiss.

For simplicity's sake we have shown only one of the five sections in Figure No. 6.

These Turbine Buckets are made by the "Lost-Wax" method of casting, which is also used in making dentures. We won't go into a discussion of foundry practice, but it will be necessary to explain this technique briefly.

A positive wax replica is produced by injection into a book-type cavity. The wax is removed from the cavity and used in making the mold. During the time the mold is baked the wax is allowed to escape leaving a negative impression in the mold into which the metal is poured. There were several of the cavities in use. Investigation of the Buckets checked revealed the data used in figure No. 6 was composed of two different cavities. Out of all fairness I should mention this was the first time we received Buckets with the cavity identified.

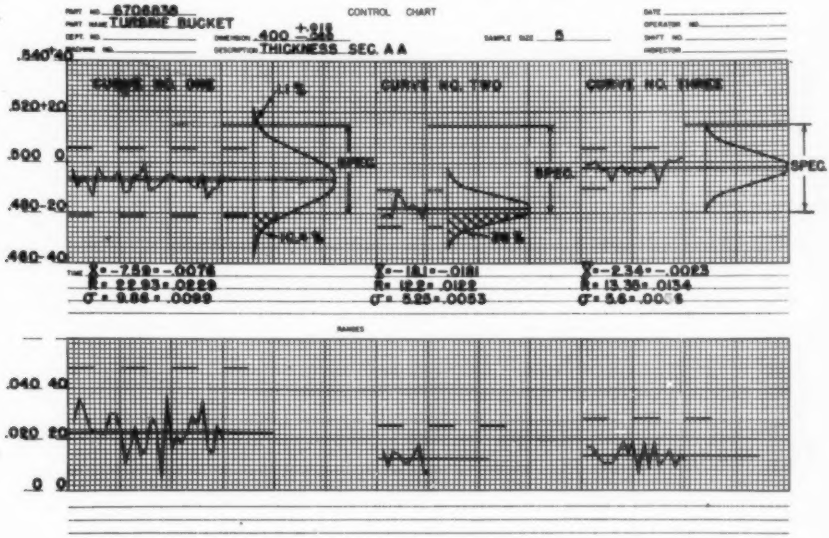


FIGURE NO. 7

Quite naturally our next step was to study the cavities individually. We were not prepared for the results that are shown in figure No. 7. The first curve shows the study of the two cavities together. The other two curves are from the two cavities studied individually, which we will call Cavity #1 and Cavity #2. Notice that Cavities #1 and #2 are approximately equal in width, but are very definitely located at different levels. Cavity #1 was producing 36% of the pieces out of the low limit, while Cavity #2 was entirely within the limits. These results lead us into the second phase of the investigation. The problem now was how to correct this condition. Before arriving at any definite conclusions we had to study all cavities individually.

Figure No. 8 shows a cavity that was studied at each section. The nominal dimensions at each section were adjusted to a common zero line and the curves were plotted plus and minus from this zero line. In this way we were able to present all the pertinent data to our Foundry Contact Department. They made the decision to have the vendor shim the cavity in such a manner to add approximately .016 at Section AA and to maintain the present level at Section EE.

After the vendor was notified they took measures to correct this condition. The cavity was shimmed, new waxes were made and buckets were produced. After a little experimenting we received buckets that had a spread of individual pieces as shown on figure No. 9. This figure is charted the same as figure No. 8.

Notice how each section meets the specification with the exception of Section AA which has 1% plus the limit and 0.8% minus the limit. This is due to the width of the curve and is not enough to be concerned about.

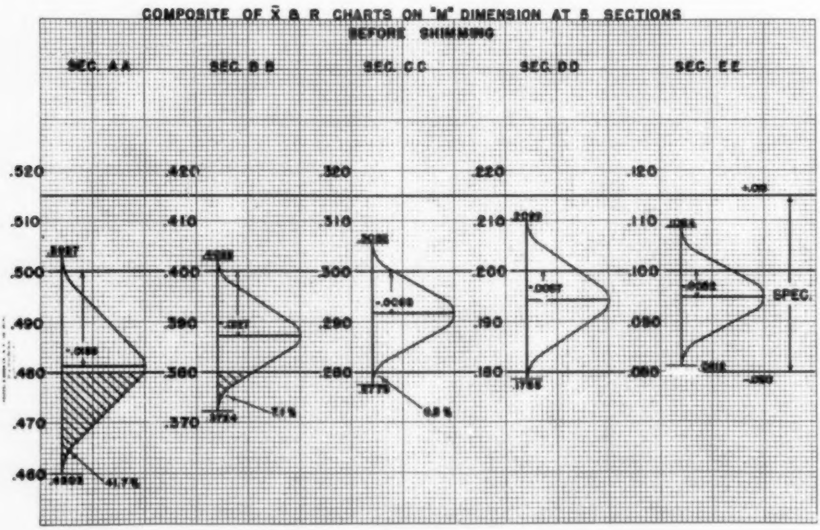
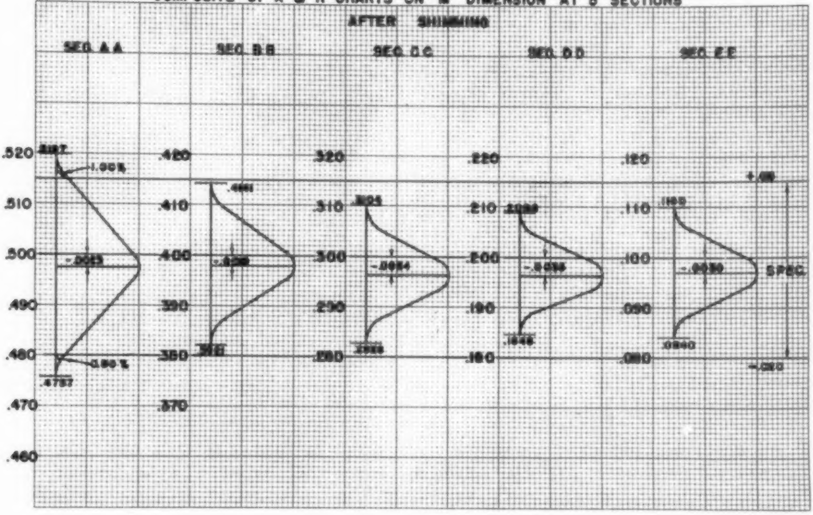


FIGURE NO. 8

COMPOSITE OF $\bar{X}$ & R CHARTS ON "M" DIMENSION AT 5 SECTIONS



TORQUE CONVERTER

Early in 1948, our Engineering Department finished the design of an improved Torque Converter model and turned the prints over to our Model Shop to build two or three units for test purposes. The units were built, tested, and after several teardowns and re-assemblies to incorporate numerous changes, were ready for final testing.

Most of the Engineering Test Specifications are established from the results obtained during the final testing. Usually there is a very limited number of observations obtainable at this time.

On this particular Torque Converter model, an Engineering Specification of X% ± 1.2% had been established as the desired efficiency. The unit was then released for production and almost immediately, difficulties were encountered in an attempt to obtain this efficiency. As is the usual case, this failure to always meet the specification resulted in considerable teardown, rework and re-assembly, which quite often failed to accomplish any noticeable improvement.

Statistical techniques were used to investigate the major characteristics which should have contributed to poor efficiencies. These studies indicated we were maintaining reasonably good control of these several major variables. Obviously, it was impractical to investigate or chart all the variables that might affect the efficiency.

After we had been in production several months and had failed to make any significant improvement in regards to the efficiency, it was decided we should build a histogram and calculate a frequency distribution curve from the values recorded from the last hundred or more Torque Converters produced. Records revealed that since the last major change we had built 129 units. Since efficiency is measured to the nearest one tenth percent (.1%), we used the same value for the cell interval when we built the histogram. The resulting histogram and calculated frequency distribution curve, as shown in figure No. 10, indicated we were producing units that formed an extremely normal distribution of efficiencies.

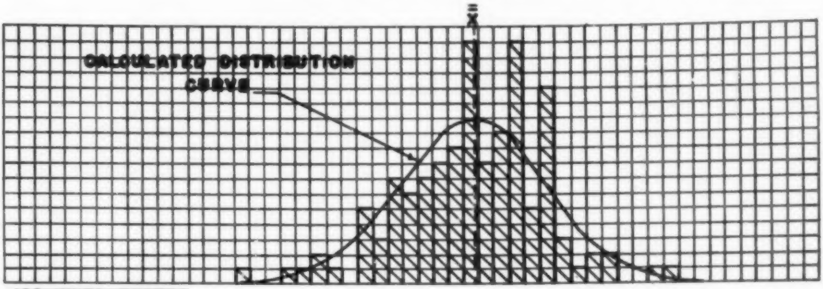
We compared this factual data with the Engineering Specification and found the mean of the actual distribution to be 1.4% minus the mean of the Specification. The six sigma spread was also found to be three percent (3%). Figure No. 11 shows the Engineering Specification with a curve idealizing the desired distribution in comparison with the distribution obtained. About 34% of the units produced were meeting the established efficiency specification with the balance of 66% falling less than that desired to an extent of 1.7%.

We now realized that we had a manufacturing process that was just not capable of producing all the units to meet the established specification. This presented us with a problem. Would we make major changes in the process? Would we revise the specification to agree with the process? Or, would we establish some salvage limit that would allow us to accept most of the units while we were making additional studies to determine which changes in process and engineering would be best in order to effect increased efficiency? We chose the latter course and established a salvage limit that permitted acceptance of virtually 100% of the units being produced while further investigation were made. We felt justified in following this course of action even though we were not meeting our desired efficiency, because the units we were producing surpassed the efficiency of comparable competitive units.

During the next few weeks, numerous intensive studies were made and we soon realized that any significant change in the efficiency level would necessitate some very expensive processing changes in addition to some engineering changes. After much discussion we decided against making these changes for two reasons. One, the increased efficiency that could be obtained did not warrant the expenditure that would have been necessary. The other, we anticipated discontinuance of this model in favor of an improved design that would be released to production. Eventually this improved model was released and subsequent testing of several production units proved it to be quite satisfactory.

Probably one more comment should be made regarding our Torque Converters. When new Torque Converter models are designed and developed it is still the policy to establish the engineering test specifications on the drafting board and from the results obtained from observations made during the final testing of model units. However, the specifications are now based upon a greater number of observations than was the practice in the past. In addition there have been several occasions where factual data gathered during the testing of production units has prompted revisions in the specification, provided the test values obtained were satisfactory.

AN EFFICIENCY STUDY AT HIGH SPEED RATIO ON A TORQUE CONVERTER EXPRESSED IN PERCENTAGE

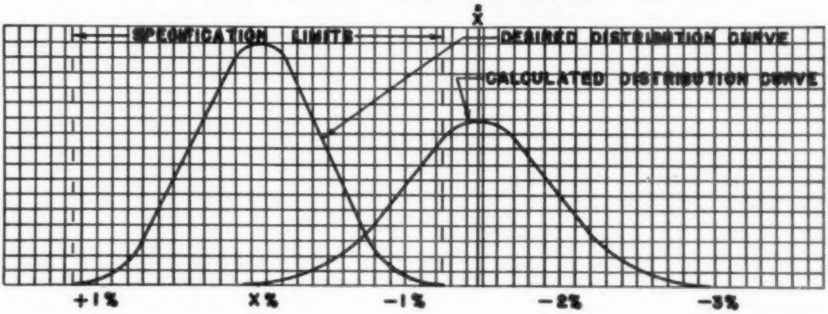


129 UNITS TESTED

CELL INTERVAL = .1 %

FIGURE NO. 10

COMPARISON OF DESIRED AND OBTAINED EFFICIENCES AT HIGH SPEED RATIO ON A TORQUE CONVERTER EXPRESSED IN (%)



129 UNITS TESTED

CELL INTERVAL = .1 %

FIGURE NO. 11

BLOWER SHAFT INVESTIGATION

For a period of three years we performed 100% inspection on the .9841 +.0000 -.0002 bearing diameter of the Blower Rotor Shaft.

A statistical study was made on some pieces in final inspection that were run-of-the-mill parts. This study indicated that the process was producing 35% of the pieces below the low limit and 3% plus the high limit. (See figure No. 12) Inspection records for the past three years confirmed this percentage. However, no one had been particularly perturbed because it had been established that pieces .0002 minus the limit were perfectly acceptable as salvage material.

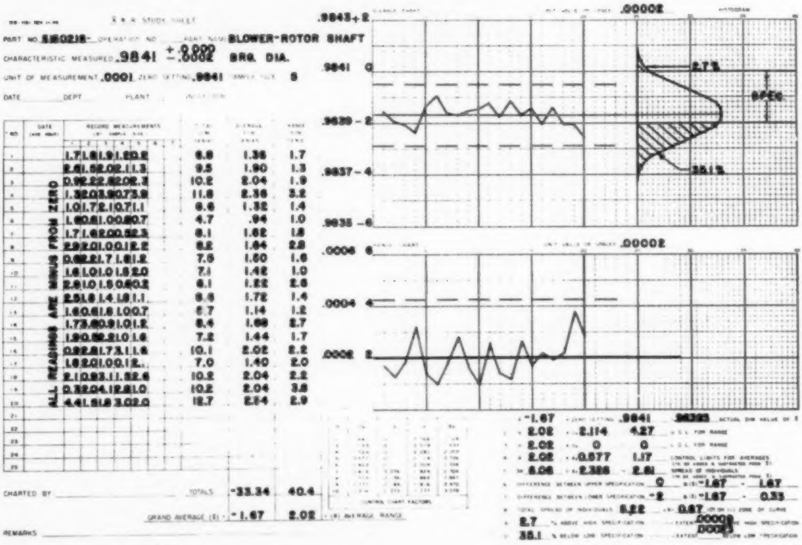


FIGURE NO. 12

This was the condition at that time. It was felt that something had to be done. After all, the fact that a piece was accepted through salvage doesn't improve the quality. Also the paper work necessary to salvage 35% of the pieces was time consuming.

We had three alternatives, live with the process, establish greater tolerances, or, thoroughly investigate the process in hope of locating the assignable cause for the extreme variation. We decided to investigate the process. Investigation revealed that the operator was dressing the wheel excessively and was experiencing difficulty in backing the wheel from the piece when the proper diameter was reached. It was apparent that maintaining a .0002 tolerance on a high production operation was not the most simple task; by any stretch of the imagination. The operator was using an Arnold gage and as the piece approached size he would back the wheel off. Figure No. 12 shows how his inconsistency had affected the overall process.

Various people were contacted and finally someone had the idea to install a micro switch on the Arnold gage, which automatically backs the wheel from the piece when the correct diameter is reached, thereby relieving the operator of this responsibility. The operator was instructed to dress the wheel and let it run until surface finish requirements made it necessary to dress the wheel again.

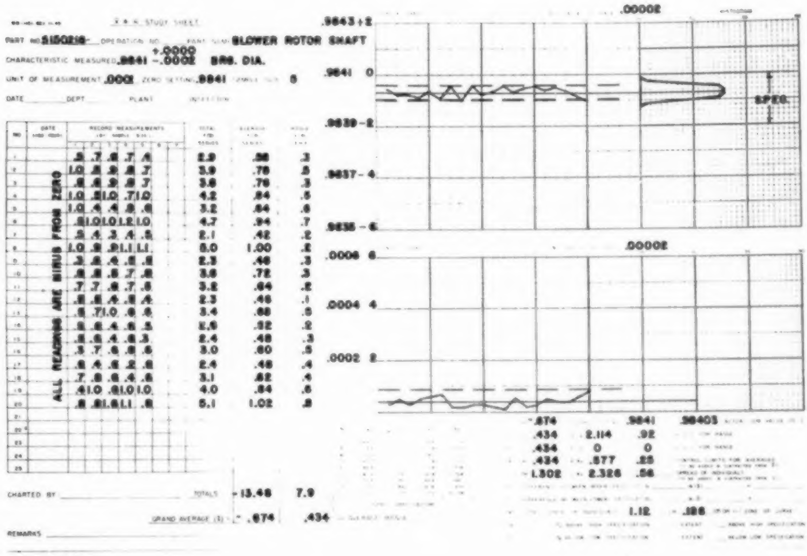


FIGURE NO. 13

The second statistical study was made from pieces produced under these changes and the results are shown in figure No. 13. This study shows a process in a good state of control and producing pieces within the specification limits. Not only are they within specification but the width of the curve is approximately one-half of the total tolerance.

What used to be a troublesome operation requiring 100% sorting and the routing of one-third of the pieces through salvage, now is being controlled at a satisfactory level. Consequently, we are able to accept pieces at reduced inspection. 60 pieces are placed in a tote pan and moved to inspection. A random sample of five pieces is selected from each tote pan and average and range points are plotted on an $\bar{X}$ & R chart. If the points fall inside the control limits, the entire pan is passed as meeting the specification. If the point or points fall outside, we resort to 100% sorting for that pan.

It would be well to point out at this time this problem, like so many others, could not have been solved without the cooperation of all concerned.

HOUSING INVESTIGATION

In December 1948, shortly after we had started making parts for Company X, we received complaints that some of the parts we were supplying did not meet the specification. We knew that we were having trouble on this particular part as well as some others but we felt sure that we were getting all that was possible from the machines and fixtures. When we had assumed this job, it was part of the contract that we use their tooling.

All this brought about the questions, "Why can't we produce pieces as good as they did using the same tooling?" and "What percentage of pieces did they make out of specification?" It was apparent that to answer these questions we would have to start somewhere. A Statistical Control man was called in to make a study on the .4665 ± .001 dimension which was particularly irritating. He recorded the readings from 100 pieces in the usual manner and made an $\bar{X}$ & R chart (figure No. 14). This chart shows that the process was very well centered, but with approximately 20% out of specification on both sides.

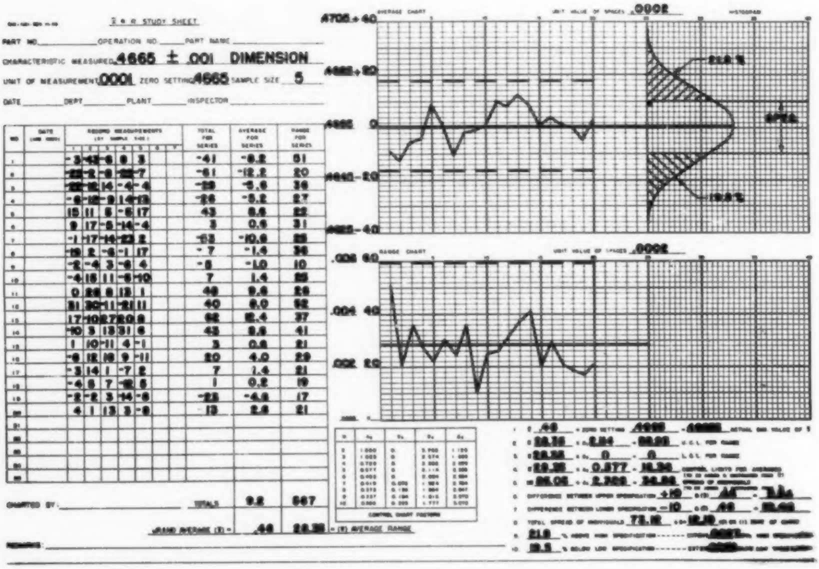


FIGURE NO. 14

We had a start toward answering the first question, but needed something to compare with this study. The records indicated that there were several hundred pieces in stores that had this operation performed by Company X.

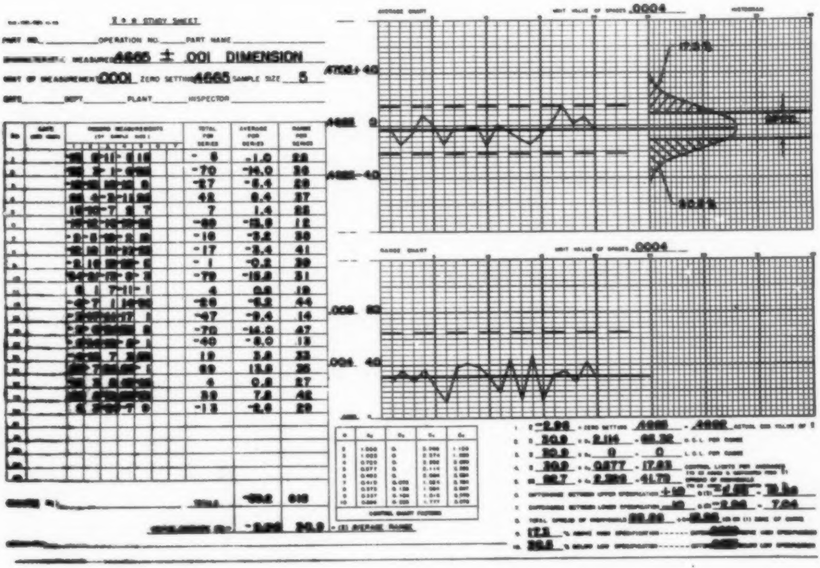


FIGURE NO. 15

Another study was made, on 100 of these pieces, and the results are shown in figure No. 15. Notice that the spread of individual pieces is comparable to the first study. It had been thought that the machines may have been damaged in transit. However, had they been damaged the increase in variation would have been reflected on these charts.

The two studies now indicated that, while the variation in both processes was approximately equal, we actually had fewer pieces requiring salvage or rework action.

We now had the facts. Both questions had been answered satisfactorily, but we were still producing pieces out of the specification limits. We were confronted with the three alternatives that often plague statisticians, "Should we live with this condition and continue reworking and salvaging pieces?"; "Should we request a review of the tolerance stack-up in hopes of getting a more realistic specification?"; or, "Should the machines and fixtures be reworked or replaced in order to reduce the inherent variation?".

The first alternative was ruled out as time consuming and unnecessary. The second seemed to have potential possibilities so our representative went to Company X, who had engineered this product, with these studies. When their Engineering Department was shown these studies, and the composite shown in figure No. 16, they decided to review the tolerance stack. After much discussion regarding this dimension, it was decided that a specification of .465 ±.002 would be close enough to insure proper performance.

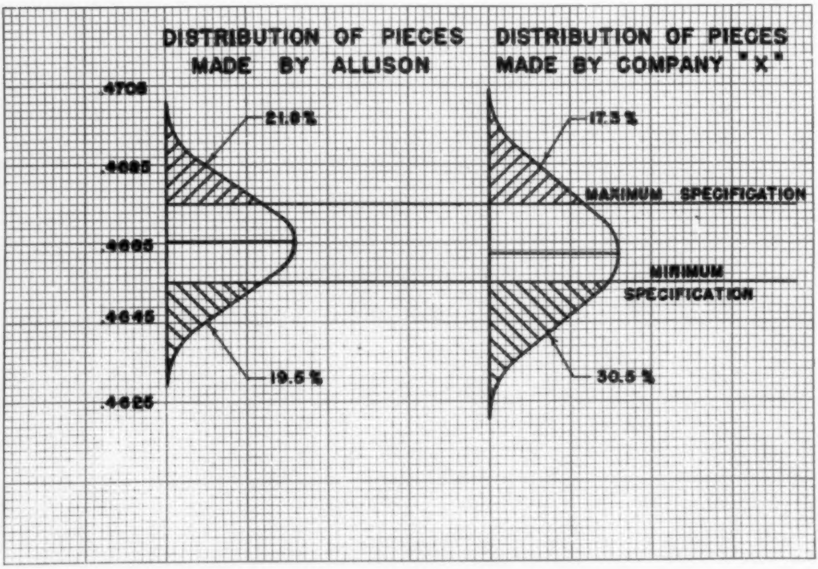


FIGURE NO. 16

The change in specification, dropped the percent defective down to 10% on subsequent production after an adjustment of process level. Quite an improvement from 41%, but still not good enough. So we finally had to resort to alternative number three and had the tooling reworked. Consequently, this operation began to produce pieces within the specification.

ALTERNATOR FIELD COIL ASSEMBLY

In January of 1949, we experienced considerable difficulty with our large Alternator Field Coil in regards to high resistance. The Production and Inspection Departments immediately tackled the situation with an aim to ferret out the assignable cause or causes. They approached the problem assuming the assignable cause would be one of two things. Either some of the items contributing to resistance would fail to conform to the engineering specifications or the high resistance would be the result of faulty assembling.

Numerous hours were expended in the re-inspection of stock, checking and reviewing the assembly methods and calling of meetings to discuss the difficulty. The re-inspection of stock confirmed that the engineering specifications were being maintained and the investigation could uncover no significant change in the method of production assembling. The meetings all adjourned with no decisions reached that would correct this condition.

FIGURE NO. 17

After several days the Statistical Quality Control Department was asked to make a study of the resistance. The first move was to gather sufficient data to construct an $\bar{X}$ & R chart for the resistance values obtained, as shown in figure No. 17. The chart clearly indicated we had a statistically controlled process and predicted that if the process continued with no change we could expect approximately 21% of the units to exceed the maximum resistance specification to an extent of .002 ohms. All those exceeding the maximum specification were not scrap because we were fortunate in having a salvage limitation that allowed about 15% of these units to be accepted. However, the 6% that was considered scrap could amount to a very high monetary loss.

Even though the $\bar{X}$ & R chart determined that we had a statistically controlled process that did not meet our requirements we had discovered nothing that would point an accusing finger toward an assignable cause. However, we were not discouraged and proceeded with the investigation. The next step was to act the role of detective by asking a lot of questions, such as, "Has there been any significant change in Production or Inspection personnel?"; "Are we manufacturing parts on different machines or under changed conditions?"; "Has there been any change in vendors or new vendors acquired?". From this last question we learned that a new vendor had been acquired. We were now buying the square copper wire used in the Coil Assemblies from two sources.

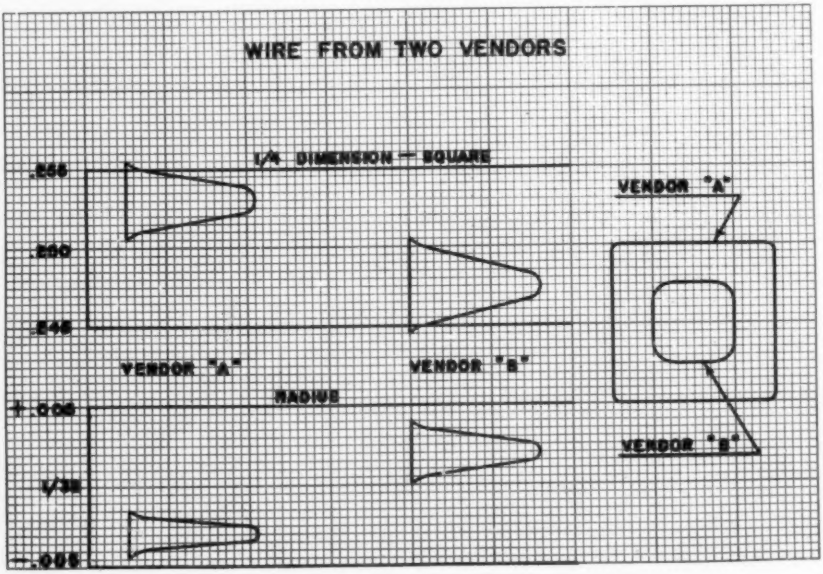


FIGURE NO. 18

A study was made on the wire received from both sources and it was found that each was being produced within the engineering specifications but at different levels. The wire from vendor "A" was near the high limit on the 1/4" square dimension while that received from vendor "B" was near the low limit. Also, vendor "A" was maintaining a minimum

radius on the corners compared to the maximum radius found on the wire from vendor "B". The distribution and levels for both are shown in figure No. 18. At this point it was decided that resistance studies should be made on assemblies using wire from vendor "A" only and assemblies using wire from vendor "B" only. Figure No. 19 shows the results of the subsequent studies and clearly indicates that a difference in resistance is to be expected from the two wires.

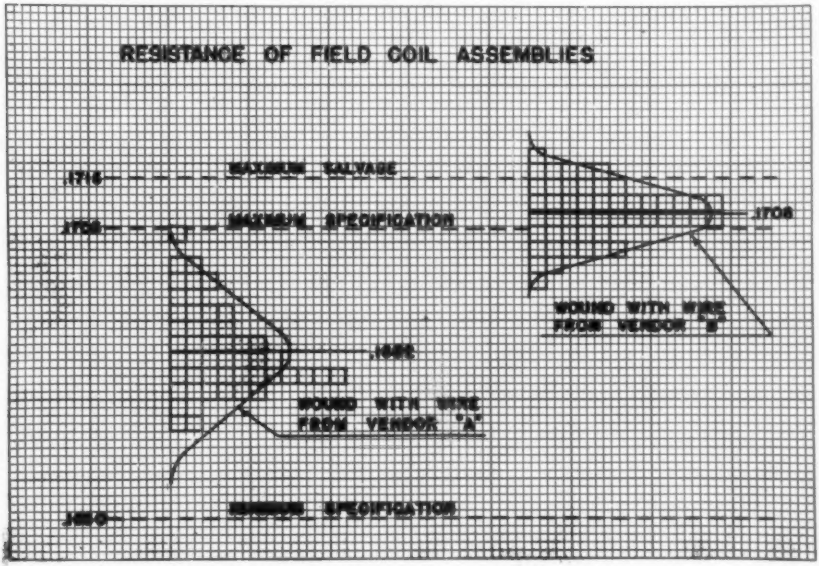


FIGURE NO. 19

Since a lot of this wire is required for each assembly, it was only logical to think that there would be differences in total assembly weight, dependent on which wire was used. This being the case it was also possible that some correlation existed between the total assembly weight and resistance. A linear correlation analysis was made and it indicated the resistance of the coil was inversely affected by the total weight of the assembly. Assemblies weighing more than average had a low resistance, while those weighing less than average had higher resistance. A scatter diagram was made which illustrated the increase in resistance as total assembly weight decreases. We realized there were several other factors involved which could also cause the weight of the finished assembly to vary, such as laminations, end plates, varnish, etc.

Because of this, it was decided an $\bar{X}$ & R chart should be maintained during the next few days for both resistance and total weight. It was thought that if the correlation of weight and resistance continued we could be definitely sure we were on the right track. Figure No. 20 is a graphic comparison of the average resistance and weight values in two hundred (200) completed assemblies as recorded in a sample size of five (5).

Figure No. 20 furnished additional and conclusive proof that resistance varied in accordance to the total weight of the assembly.

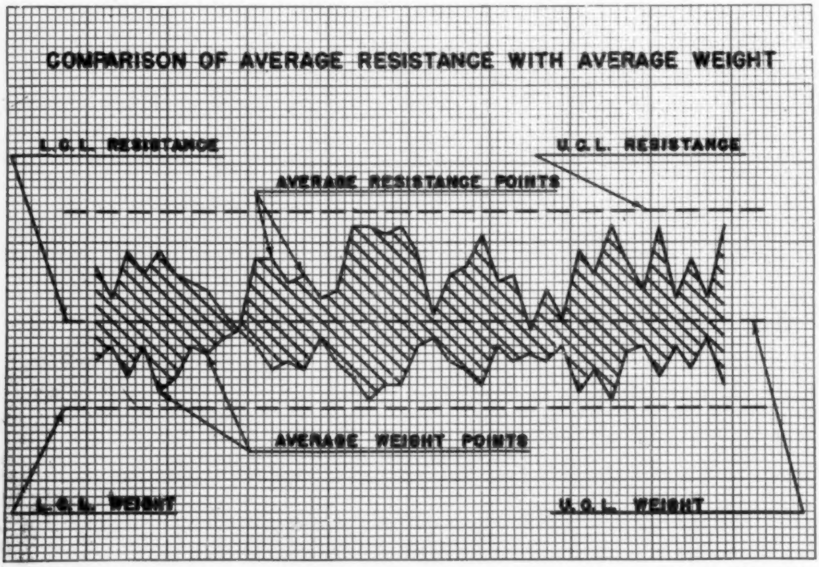


FIGURE NO. 20

This unit we were producing was designed and engineered by our customer, so it was necessary that we present our problem to him. All the data gathered during the investigation was laid before his people and we carefully explained the situation. They were able to provide the corrective action by establishing resistance specifications correlated to specified total assembly weights.

This action enabled us to accept virtually all the assemblies that had been set aside because of high resistance. We have estimated that this investigation resulted in several thousand dollars savings during the next year.

FUND RAISING DRIVES

Statistics is a science of numbers and anything that can be assigned a numerical value can be applied to statistical control techniques. Usually when one thinks of statistical control, his mind automatically switches to the product he is manufacturing and the control of that product from a quality standpoint. Now, it's agreed this is of prime importance in the amortization of your S.Q.C. program. However, in doing this many ramifications are overlooked.

In selecting solicitors for fund raising drives, care is usually exercised to choose someone who has the proper attitude toward these drives. However, sometimes a mistake is made. This story deals with such a mistake.

We had six solicitors who contacted different departments. These departments are different only in the respect they handled different parts. All other things were comparatively equal; pay scale, working conditions, etc.

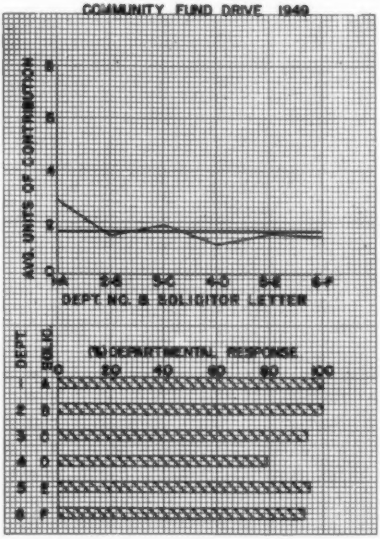


FIGURE NO. 21

In October 1949, the Community Fund Drive had 93% of response and an average contribution of X dollars (see figure No. 21). The individual percent of response was more or less equal except in one case, Solicitor "D" who had 79% of response. This chart was primarily used for a graphical report and no particular significance was attached to the low percentage of response of Solicitor "D". In March 1950, during the Red Cross Drive, the same Solicitors were used except that a substitute was used for the regular Solicitor "C". In figure No. 22 you will notice there were two solicitors who had low percentage of response. The net result was that the overall percentage of response dropped 5%. The average contribution dropped 23%.

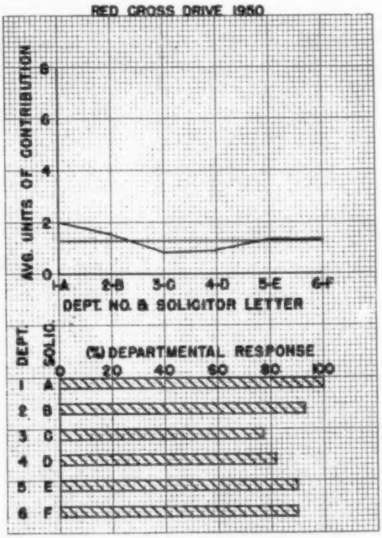


FIGURE NO. 22

In the analysis of the two charts (figure No. 23) there were two outstanding questions. One was, "Did Solicitor "D" have more than her share of uncooperative people?", or, "Was her approach improper?". This question could not be answered at this time because Solicitor "D" had contacted the same group of people both times. The other question was, "What significance did the substitute Solicitor "C" have upon the percent of response?". The substitute solicitor was selected in an emergency and did not have the proper qualifications for this type work. The Superintendent had been notified at the last minute to furnish someone to go on a publicity tour of the various organizations that receive benefits from the Red Cross. He had to select someone who was wearing a dress rather than slacks. This rather limited the field and the normal qualifications had to be overlooked.

By the time the 1950 Community Fund Drive came along we decided to change Solicitor "D" from the department she had been soliciting to another department. The departments are closely related and she was acquainted with these people also. Solicitor "C" was available so that eliminated the necessity of the substitute.

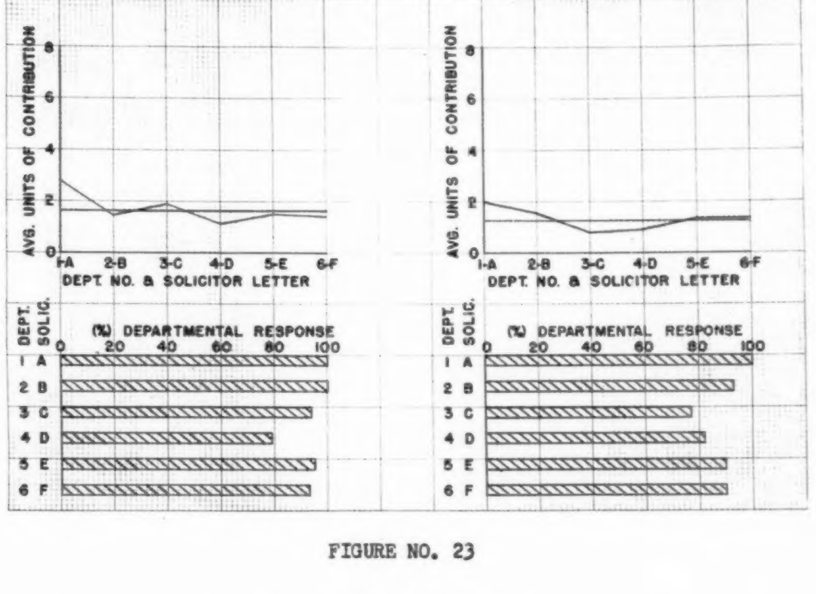


FIGURE NO. 23

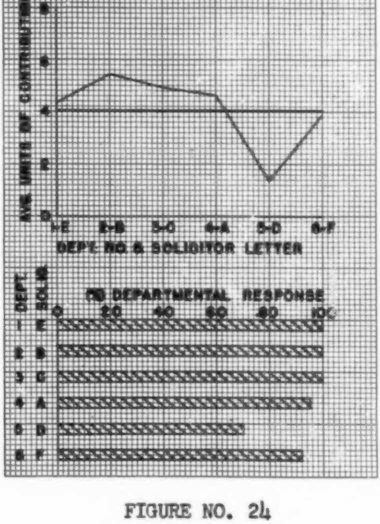


FIGURE NO. 24

Figure No. 24 shows that the average contribution was up 140% from the 1949 Community Fund Drive and 211% from the 1950 Red Cross Drive. The percentage of response was 92%, which is comparable to the first drive percentage of response and was 4% above the second drive percentage of response. Solicitor "D" had a percentage of response of 70%, while Solicitor "A", who contacted the department formerly contacted by Solicitor "D", had a percentage of response equalling 92%. Hence, the conclusion was that Solicitor "D" appeared to be suited for soliciting but actually was not. Figure No. 25 shows a comparison of all three drives.

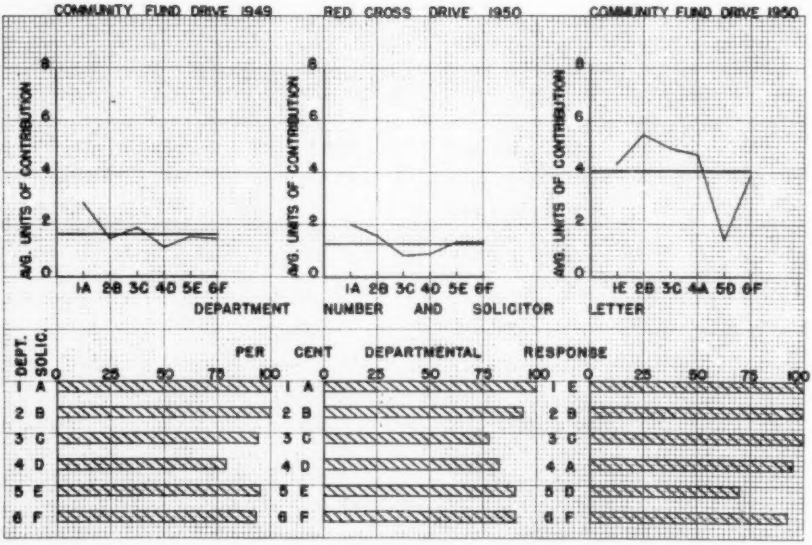


FIGURE NO. 25

In summarizing, I want to point out that (6) of the (7) examples used were chosen, two each, from our Aircraft Engine, Electro-Motive Parts and Transmission Plants. They were chosen because of their basic simplicity and characteristic differences in addition to their geographic separations. The seventh was strictly a "By-Product" of our Statistical Quality Control program. We feel there are many "By-Product" activities in modern Industry, evaluation of which can be determined by the use of statistical quality control techniques.

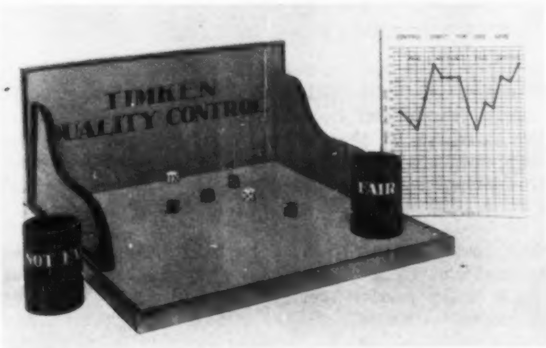
MECHANICAL AIDS FOR PRESENTING THE QUALITY CONTROL STORY

Robert E. Wagenhals
The Timken Roller Bearing Company

This article contains brief descriptions and suggestions for the use of mechanical devices which aid Quality Control instruction. The devices were constructed and have been used successfully by The Timken Roller Bearing Company.

The presentation is accomplished by the use of a skit which illustrates some of the problems encountered when selling Quality Control to management. Taking part are R. E. Wagenhals and L. D. Rice.

DICE GAME CONTROL CHART DEMONSTRATION



The control chart can be applied to data from many sources. This is emphasized when a chart is made for a dice game. Most shop personnel are familiar with some dice games and interest is arroused.

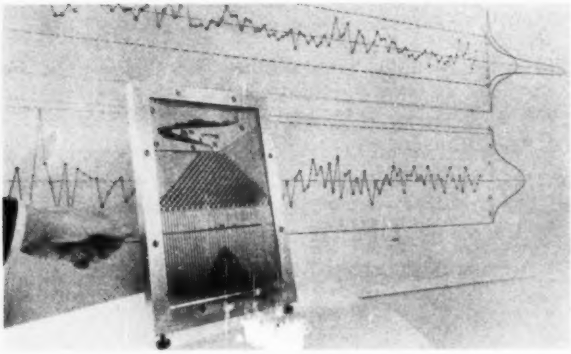
Two sets of 6 dice are used. One set is fair, the other is unfair having on each die 2 sixes, 2 fives, one four, and one three. These dice are rolled from cups onto a board 18" by 18" with sides and back. All surfaces touched by the dice are covered with linoleum.

The object is to determine when unfair dice have been substituted for fair ones or vice versa by charting the total spots on the six dice. Changes are detected within three or less throws by plottings either beyond control limits or groups of two or three very near the control limits. Limits are 13.7 and 28.3.

A person from the audience is usually asked to throw the dice and add up the spots. He may make the change at his will and allow at least a few witnesses to see the change. The demonstrator keeps his back to the dice board and the chart shows him when the change is made.

Control chart principles illustrated are: (1) plotting points and constructing the graph, (2) plottings normally remain within certain limits, (3) plottings will fall beyond or be grouped near a control limit when the process is changed.

THE QUINCUNX OR PIN BALL MACHINE



The normal curve is fundamental to all Statistical Quality Control Methods and its presentation must be made very early in any training program. Many examples of this most useful curve can be found if a series of measurements or observations are made. Often the examples used seem far-fetched to the trainee and he may be reluctant to accept them without some very concrete demonstration.

The quincunx, originally invented by Galton, is a very effective help in this demonstration. The steel balls dropping through the maze of pins behave in a truly random manner and will form a good approximation to the normal curve.

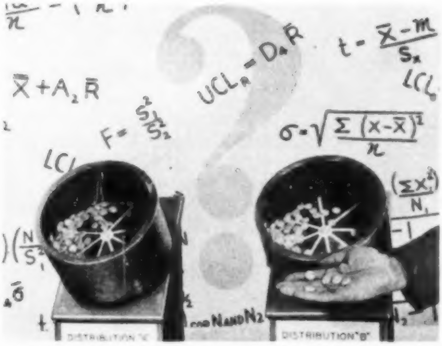
The machine is small enough that it may be easily carried and set up on a desk or small table. The balls, blackened by "Black Magic" (which is a trade name) form a distribution easily seen at a distance up to 30 or more feet.

If more information about the normal curve is desired, the average and standard deviation may be calculated for the group of balls. The expected number in each of the "sigma limits" - plus and minus one sigma, plus and minus two sigma, or plus and minus 3 sigma - can be calculated and compared with the actual numbers in the groups. In all demonstrations these numbers have been very close.

Data may also be obtained with the quincunx to illustrate $\bar{X}$ and R control charts. Samples of the desired size may be obtained by releasing a series of balls which will be stopped by the wire. After the slot numbers in which the balls have fallen is recorded and averages and ranges calculated, the balls are released by pulling out the wire. Other "samples" may be obtained in the same manner until enough have been obtained.

The general average, $\bar{\bar{X}}$, and average range, $\bar{R}$, and control limits are then calculated. Points may be ploted as data is obtained or after all data is obtained. The chart will very likely show the quincunx to be in control.

CHIP MIXERS



The problems of thoroughly mixing a set of numbered chips and holding the attention of the audience are both solved in a dramatic manner by using one or two mechanical Chip Mixers.

Mixers are easily constructed by mounting mixing drums on electric phonograph turntables which are in turn mounted on inclined bases. The bottoms of the drums are conical in shape and the entire inner surface is lined with velvet cloth to reduce the noise. The mixer is designed to handle 200 chips 5/8" in diameter but quantities from 50 to 600 can be mixed with good results. Some uses are:

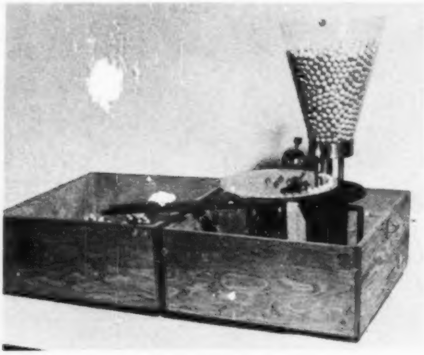
(1) Draw chips in groups representing samples, calculate $\bar{X}$ and R and construct a control chart. If additional chips numbered to represent out of tolerance pieces are now added to those in the mixer and more samples taken, the chart will soon be out of control. This effectively illustrates how the control chart indicates trouble with a process.

(2) Chips forming a rectangular or triangular distribution are placed in the mixer and samples of 4 or 5 pieces each are drawn. Averages are calculated and a tally is made. This tally soon indicates that the averages form a distribution that is nearly normal even though the distribution of individuals is very different. This demonstration illustrates that control chart calculations, based upon the normal distribution, are valid under practically all industrial conditions and even when processes are definitely out of control.

(3) Two Mixers may be used to illustrate Test of Significance, such as the F test and the t test. Two different distributions of chips are used and a sample is drawn from each.

The required number of measurements to reach a desired significance level can also be determined.

100% INSPECTION MACHINE



In the introduction of Statistical Quality Control into a manufacturing plant sooner or later some form of sampling inspections will be investigated, found applicable, and will have to be sold to management as well as regular line inspectors. This selling job will be especially difficult for people in factories manufacturing precision products which have been 100% inspected. To do anything less than 100% inspection is an admission that some product of sub-standard quality is going to be missed and hence, many people think of it as a step in a backward direction.

The only valid attack to this problem is to show that 100% inspection does not result in 100% PERFECTION.

The 100% Inspection Machine causes 3000 white plastic balls to pass by the inspector who is a volunteer from the trainee group, in approximately 25 minutes. The balls are rolled and turned in such a manner that all parts are presented to the inspector's view. The requirement is to pick out the defectives as they roll by.

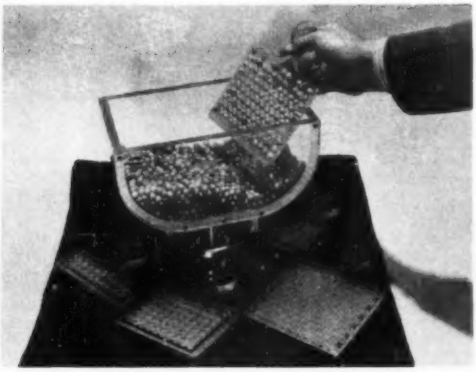
Balls of 4 types are used: (1) 2000 solid, (2) 700 drilled, (3) 300 drilled and filled with a brass pin, and (4) 100 drilled and filled with a steel pin. The balls with the steel pin are classed defective.

A strong magnet placed in the box in such a position that all the balls pass near it will pick out any "defectives" that the inspector misses. In this way the efficiency of the inspector can be easily determined. For example: if 7 balls with the steel pin are missed the number found is 93 or 93% of the total defective pieces.

Our experience has been that only one person picked out all 100 defectives and he had tried it several times before. Others have missed from 1 to 17 with the average about 92%.

The machine is small enough to be carried easily, is driven by a small electric motor and has a lamp attached to give uniform lighting conditions in all rooms. It can be set up on an office desk or in the front of a lecture room.

SAMPLING



Some form of sampling has been used by nearly all manufacturers who are engaged in mass production. They have found that 100% inspection is not economical and many have come to realize that defective material will be passed even though every part is supposedly inspected.

The sampling methods used vary considerably, some being of little or no value, others moderately effective but uneconomical, and still others very efficient. One of the most common types has been "ten percent sampling". This is found to be generally unsatisfactory when its operation is studied over a period of time.

Various sampling plans can be demonstrated and evaluated with a group of white and red plastic balls 7/16" in diameter. The red balls represent defective material and the white OK material. These balls are mixed in a plexiglass bowl. Sampling paddles containing different numbers of pockets are also made of plexiglass. The equipment has a very pleasing appearance and helps create interest in the demonstration.

A series of sampling plans have been devised to evaluate 10%, single, double, and sequential sampling. The bowl contains 1500 balls, 4% being red. This lot is considered acceptable.

Sampling plans are shown in the following table.

Type of Plan	Sample	Sample Size	Acceptance Number	Rejection Number	Ave. % of Actual Lots Accepted	Theoretical Percent of Acceptance
10%	1st	150	6	7	68	62
Single	1st	115	8	9	96	95
Double	(1st	75	5	12)	94	95
	(2nd	150	11	12)		

Twenty drawings for each plan are adequate to verify the theoretical percentage of acceptance.

ASSEMBLY TOLERANCES

An assembly of several parts must be held within certain over all tolerances and, of course, each individual component has its limits also. This is true of many products as, for example, thickness of automobile leaf springs, thickness of tires (4 ply or 6 ply), plates of a radio variable condenser.

The usual engineering procedure is to divide the overall tolerance among the several parts so that the sum of all the tolerances will equal that of the assembly.

Since the component parts are often made on separate machines and in fairly large quantities the assembly is made from a random selection of parts. Parts are taken from bins and assembled with little or no consideration given to size. These assemblies must conform to specifications.

If processes producing individual parts are in control a very real advantage may be gained in that (1) individual tolerances may be widened or (2) the assembly tolerance may be tightened. Either advantage may be obtained depending on conditions of use of the assembly or manufacturing difficulties.

Without going into any mathematical explanation, this demonstration proves that most completed parts will conform to considerably smaller tolerances than those which are called the "absolute" or the total of all component tolerances.

A number of parts painted in 5 colors - red, blue, yellow, green, and brown are used. A pile consisting of one piece of each color represents an assembly. Each group of one color represents a controlled process in that the frequency distribution closely follows the normal curve.

When the largest piece of each color is selected the stack reaches the upper black line on the backboard. Likewise the smallest pieces reach the lower black line. Any other stack of pieces must be of some intermediate height.

The parts of each color are mixed together and a piece from each group is selected at random. In practically all cases the assembly formed will reach somewhere between the red dotted lines marking the "natural tolerances".

If truly random selections are made from each color the chances of getting a pile outside these natural tolerances is about the same as getting a point beyond the limits on a control chart, namely about 3 in 1000.

MIL STD 105A - A STANDARD ACCEPTANCE INSPECTION SYSTEM

Commander B. L. Lubelsky, Director
William R. Pabst, Jr., Assistant for Statistics
Quality Control Division, Navy Department

Military Standard 105A, the new sampling tables for inspection by attributes, will probably be used as the basis for acceptance inspection of more products dollarwise than any other inspection system used in the past. The new standard, a joint action of the Army, Navy and Air Force combining the many separate sampling plans previously in force, will be used in the acceptance inspection of all military purchases where such inspection is appropriate. The new standard is also being used to an increasing extent by private industry for acceptance inspection under government sub-contract and in acceptance inspection for ordinary commercial products. It, therefore, becomes important to understand the objectives of the standard inspection system, the character of its application in a centralized organization such as the Bureau of Ordnance and those areas of application in which refinement are necessary. These topics will be discussed in turn.

Section I Objective of MILITARY STANDARD 105A

The objective of a standard acceptance inspection system is to judge and evaluate given material offered for purchase regardless of where the item is produced and to inspect and uniformally accept material which meets government requirements and uniformally reject all material which does not meet these requirements. This should be accomplished with preset risks of error and with minimum total cost.

This objective can be attained only by the provision of necessary standards that can be followed throughout the entire inspection organization. These standards can be identified as follows:

(1) A standard for the item to be inspected
This standard is usually given in the Classification of Defects for the item in question which indicates the relative importance of each dimension specified on the item and for all departures from these specified dimensions. A defect is defined as any deviation of the unit of product from requirements of the specifications, drawings, purchase descriptions and any changes thereto in the contract or order. The Classification of Defects (or CD) brings to bear for the use of the inspector the judgment of the designer as to the relative importance of the different dimensions and tolerances assigned.

(2) A standard for a lot of items to be inspected
The lot standard is provided directly in the sampling plans for lot acceptance so that each inspector will use the same sample size for a given lot size and at a given acceptable quality level (or AQL) will use the same acceptance or rejection number in making a decision to accept or reject the lot.

(3) A standard for average quality of material over a series of lots
This standard is furnished by means of process average control which sets the level at which the inspector will use the past production history as a guide to the amount of inspection necessary. Good product quality makes it possible to decrease the amount of inspection required and poor production quality makes it necessary to obtain greater protection against the acceptance of inferior materials.

(4) A standard for the inspector
This standard is a reflection of the material standards imposed so that each inspector, no matter where located, will have the same basic means of making a decision for acceptance or rejection without resort to special knowledge or special consideration.

(5) Standard for Manufacturer
This standard is also derived from the standards for the item product and the

standards for lots, since these indicate clearly the goal for which the manufacturer must strive in order to get maximum product accepted and minimum amount rejected.

The new Military Standard 105A by itself supplies only part of this series of standards required for a standard inspection system, that in the form of standard sampling tables based on known risks of sampling error which provide directly the basis for the lot standard and the process average standard. Its effectiveness as a standard must rest on the adequacy of the item standards and the administrative procedures to assure standard conformance on the part of inspectors and on the part of manufacturers in carrying out their responsibilities.

Because of the importance of these supplementary administrative details and requirements necessary to make an acceptance inspection system upon the framework of the MIL STD 105A, in fact a standard system. The procedures used by the Bureau of Ordnance are described in some detail.

Section II Bureau of Ordnance Procedure for Use of MIL STD 105A

Acceptance inspection of Bureau of Ordnance material is now largely based on the methods and procedures of MIL STD 105A. When a contract is assigned for the production of material on the part of a contractor, inspection cognizance is assigned to a government inspector who is furnished with the necessary information to carry out inspection on the basis of the standard. When a project order is assigned to a Naval Ordnance Plant, a similar set of instructions is sent out. The specific steps which are taken by the Bureau and by the inspector can be summarized as follows:

(1) Action by the Bureau of Ordnance

(a) Award of the contract by the Contract Division based upon the production of material covered by a specification developed by the Research and Development Division.

(b) The assignment of inspection cognizance by the Quality Control Division. Cognizance on a contract may be assigned to an INSMAT, INSORD or BAR or to any other government inspection agency depending upon the location and the nature of the contract.

(c) Decision by the QC Division as to whether inspection under MIL STD 105A is applicable to material produced under the contract. Generally, all production contracts are included and Research and Development contracts are not. Special classes of production materials are treated under complex item inspection, which will be discussed later.

(d) If MIL STD 105A applies, indication to inspector of applicability of normal inspection procedure. Normal inspection procedure (Exhibit 1) details the action to be taken by the inspector in the level of inspection, the type of sampling to be used, the AQL applicable, the procedure for critical defects and the submission of reports.

(e) Furnishing of the CD's for the Item (Exhibit 2). The Classification is generally made up between design agency along with drawings and other requirements at the time when new products are designed. Classification of defects for old type items if not available at the start of production may be improvised by the inspector charged with the inspection of the item. An attempt has been made in the past few years to bring classifications up to date with respect to items of current requirements. Once a CD has been approved for an item, it is used for the acceptance inspection of that item, wherever produced.

(2) Action taken by the Field Inspector

(a) Arrange for the size of inspection lot based upon the plant lay-out and production plans.

(b) Arrange for inspection stations so that each piece-part or item or sub-assembly or final product may be inspected at a level where defective material can be most easily detected and where such detection will result in the minimum amount of scrap, expenditure of labor or loss of production.

ENCLOSURE

SUBJ: NORMAL INSPECTION PROCEDURE FOR BUREAU OF ORDNANCE MATERIAL

REF: (A) MATERIAL INSPECTION SERVICE, USN, ADMINISTRATION MANUAL, PART D, CHAPTER 4 (NAVEXOS P-120-D4)
(B) JAN-STD-105, SAMPLING INSPECTION TABLE FOR INSPECTION BY ATTRIBUTES

1. REFERENCE (A) EXPLAINS THE GENERAL PRINCIPLES UNDERLYING THE USE OF SAMPLING INSPECTION TABLES. THE SAMPLING INSPECTION TABLES OF REFERENCE (A) HAVE BEEN REPRODUCED IN REFERENCE (B).

2. THE INSPECTION PROCEDURE FOR CRITICAL DEFECTS BASED ON REFERENCE (A) IS PRESCRIBED AS FOLLOWS:

A. TYPE OF SAMPLING:	SINGLE
B. SAMPLE SIZE:	1. FOR INSPECTION LOT SIZES OF 150 UNITS OR LESS - 100% OF THE LOT 2. FOR INSPECTION LOT SIZES OF 151 TO 3200 UNITS - 150 UNITS 3. FOR INSPECTION LOT SIZES GREATER THAN 3200 UNITS - AS INDICATED BY THE SAMPLE SIZE LETTER FOR INSPECTION LEVEL III, TABLE I, OF REFERENCE (B)
C. REJECTION CRITERIA:	REJECT INSPECTION LOT FOR ONE (1) OR MORE CRITICAL DEFECTIVES FOUND IN THE SAMPLE

3. THE INSPECTION PROCEDURE FOR MAJOR AND MINOR DEFECTS BASED ON REFERENCE (A) IS PRESCRIBED AS FOLLOWS:

A. TYPE OF SAMPLING:	SINGLE, DOUBLE OR SEQUENTIAL AS DETERMINED BY THE INSPECTOR AND/OR COMMANDING OFFICER IN ACCORDANCE WITH ARTICLES D4.02.02A AND D4.02.03C OF REFERENCE (A)
B. INSPECTION LOT SIZE:	AS DETERMINED BY THE INSPECTOR AND/OR COMMANDING OFFICER IN ACCORDANCE WITH ARTICLE D4.02.04B OF REFERENCE (A)
C. INSPECTION LEVEL	III
D. REDUCED OR TIGHTENED INSPECTION	AS DETERMINED BY THE INSPECTOR AND/OR COMMANDING OFFICER IN ACCORDANCE WITH ARTICLES D4.02.04D AND D4.03.02.3.14 AND 15 OF REFERENCE (A)
E. AQL MAJOR:	.65 - 1.2 PERCENT DEFECTIVE
F. AQL MINOR A:	2.2 - 3.2 PERCENT DEFECTIVE
G. AQL MINOR B:	NOT PRESCRIBED

4. IN CONNECTION WITH MINOR B DEFECTS ONLY SPECIAL GAGES WILL NOT BE SUPPLIED AND REPORTS OF INSPECTION ON NAVORD FORM 1896 ARE NOT REQUIRED. THE INSPECTOR AND/OR COMMANDING OFFICER IS REQUESTED TO REJECT THOSE INSPECTION LOTS FOR MINOR B DEFECTIVES WHERE HIS EXPERIENCE AND JUDGMENT INDICATES THAT THE DEFECTIVE RATE IS INCONSISTENT WITH HIGH PRODUCTION STANDARDS AND/OR THAT THE CAUSE FOR THE DEFECTIVES HAS NOT BEEN REMEDIED BY THE PRODUCER.

5. UNLESS OTHERWISE DIRECTED, THE PROCEDURE OUTLINED IN PARAGRAPHS 2, 3 AND 4 SHALL BE USED IN THE ACCEPTANCE INSPECTION OF MATERIAL SUBMITTED BY THE CONTRACTOR UNDER SUBJECT CONTRACT. IF IN THE OPINION OF THE INSPECTOR AND/OR COMMANDING OFFICER CONDITIONS DO NOT JUSTIFY SAMPLING INSPECTION, THE BUREAU OF ORDNANCE SHALL BE ADVISED OF THE INSPECTOR'S AND/OR COMMANDING OFFICER'S RECOMMENDED INSPECTION PLAN.

6. ORDNANCE CLASSIFICATION(S) OF DEFECTS WILL BE FORWARDED FOR EACH CONTRACT AND/OR ORDER IF AVAILABLE. PENDING RECEIPT OF, OR IN EVENT THERE IS NO CLASSIFICATION(S) OF DEFECTS AVAILABLE, THE INSPECTOR AND/OR COMMANDING OFFICER IS REQUESTED TO PREPARE A TENTATIVE CLASSIFICATION OF DEFECTS ON NAVORD FORMS 1942 AND 1942A AND SUBMIT THE ORIGINAL AND TWO (2) COPIES TO THE BUREAU OF ORDNANCE.

7. IT IS FURTHER REQUESTED THAT WEEKLY REPORTS OF INSPECTION BE SUBMITTED TO THE BUREAU OF ORDNANCE ON NAVORD FORM 1896 (NEW 6/48).

EXHIBIT II

NAVORD OCD Dwg. 515762
No REVISION
SHEET 1 of 2 SHEETS
Applicable to: BuOrd Dwg. 515762 Rev A
and O.S. 675 Rev F

ORDNANCE CLASSIFICATION OF DEFECTS

FOR

3/50 CARTRIDGE TANK MK 12 MOD 0
(GENERAL ARRANGEMENT)

APPROVED				
DIVISION	BRANCH	INITIALS	DATE	DEPARTMENT OF THE NAVY BUREAU OF ORDNANCE WASHINGTON 25, D.C.
RESEARCH	Re1	HTD	10-2-50	DATE: 4 OCT.1950.
MATERIAL	Ma3	J	10/3/50	B L Subelsky
QUALITY CONTROL	Qcc	AFM	10/4/50	By direction of the Chief of the Bureau

For NAVORD OCD's for drawings covering related assemblies, sub-assemblies and components see L.D. SK 261154

A. All figures are in inches unless otherwise indicated
B. All figures are dimensions unless otherwise indicated

CRITICAL

None

MAJOR

101. Presence of material defects (cracks, tears, etc.)
102. Supporting tube missing
103. Poor engagement of cover assembly with body assembly
104. Leaks with 5 psi or less internal air pressure
105. Top ring insecurely attached to body (poorly flanged, expanded and/or dimpled)

MINOR A

201. Cover does not turn freely on cover ring after disengagement from tank
202. No grease between ring and cover
203. No talc or soapstone on exposed bearing surface of gasket
204. Dents, bulges, deformed bottoms, etc.
205. Improper painting
206. Out of round
207. Gasket improperly cemented
208. 5.960 ± .020 Outside dia. of bottom
209. 5.900 ± .015 Outside dia. of top ring
210. 6.350 ± .015 Outside dia. of flange on top ring
211. 20.687 ± .050 Overall length

MINOR B

301. 2.30 Length of top ring
302. 1.50 Length of bulge on bottom
303. 18.770 Approx. from cover to bottom
304. Cover fastening wire missing

(c) Arrange for handling of rejected lots by manufacturer with respect to salvage, reinspection or other disposal.

(d) Determines the character of the sampling plan to be used in the acceptance of each lot, single sampling being used when a constant load of inspection can be economically handled and multiple sampling methods when intermittent inspection at a lower average level than single sampling can be made at lower total inspection costs. Single, double and sequential sampling plans and their respective advantages are discussed elsewhere. [1]

(e) Arrange to record inspection information (usually by means of attribute control charts) so as to have at hand reliable background history of process average quality information.

(f) Submits reports on lot inspection to the Bureau covering designated periods of time or a given number of lots produced. (Exhibit III)

(g) Decides to impose normal, tightened or reduced inspection based on process average information available.

(3) Action taken by the Bureau on inspection reports

(a) Tabulation of periodic inspection reports on IBM cards for purposes of summary and sorting.

(b) A statistical analysis of data from contracts indicating the homogeneity of lots, trends in quality and possible avoidance of the rejection number on the part of inspectors, etc.

(c) Preparation of inspection summaries by inspection districts and by type of product to maintain overall quality control of material inspection. (Exhibit IV)

(d) Technical follow-up of areas of difficulty shown in inspection reports leading to contract revision, production engineering, retooling, improvement of production processes, etc., in order to insure necessary quality.

(e) Review of process average information for adjustments of AQL's where found necessary from fleet requirements or on the basis of production experience.

Let us illustrate this procedure by a practical example. Recently, a contract for production of rocket heads was assigned to the XYZ Corporation in Detroit. The inspection cognizance was assigned to the INSMAT, Detroit. Normal inspection procedures were sent for this item since it was decided that the MIL STD 105A was applicable. In addition, the Classification of Defects for the item, it being a separate piece part, was furnished along with the drawing and other requirements noted in the contract.

The inspector after review of plant facilities for production of the item decided upon inspection lot of approximately 2000 units each, this being approximately a day's production on any line. Because the services of one inspector was required full time for the operation, single sampling providing a constant load of inspection was also indicated. By reference to MIL STD 105A, the inspector found that normal inspection requiring a sample size of 150 for major and minor defects. (Exhibit IV) At the 1% AQL for major defects, the acceptance number of defectives in the sample of 150 is found to be 4 and rejection number 5. At the AQL of 2½% for minor defects, the acceptance number is 8 and rejection number is 9. For critical defects, the sample size is 150 and the acceptance number was 0 defectives. Thereupon, inspection procedures were carried forward on the basis of the Classification of Defects and

*1 Freeman, Friedman, Mosteller and Wallis, "Sampling Inspection", McGraw Hill, N.Y. 1948

EXHIBIT III

WEEKLY SAMPLING INSPECTION REPORT NAVORD FORM 1096 (REV 6/48)

FROM: Inspector of Naval Material, New York | FOR PERIOD 3/5/51 to 3/9/51

TO: The Chief of the Bureau of Ordnance (Quality Control Division--QC)

CONTRACT OR ORDER NUMBER	CONTRACTOR OR MANUFACTURER	ITEM (Name) (Drawing No.)	CLASSIFICATION OF DEFECTS NUMBER
NOrd 000000	Costello Specialties Inc.	Lie Detector Mk 6 Mod 4 711711	

ACCEPTABLE QUALITY LEVELS			TYPE OF SAMPLING (Check One)	TYPE OF INSPECTION (Check One)
MAJOR	MINOR A	MINOR B	[X] SINGLE [ ] DOUBLE [ ] SEQUENT	[X] NORMAL [ ] REDUCED [ ] TIGHTENED
1.0	2.5	4.0		

LOT NO.	QUANTITY SUBMITTED	SAMPLE SIZE LETTER	FIRST SAMPLE					ADDITIONAL SAMPLES					QUANTITY	
			*SAMPLE SIZE	NO. OF DEFECTIVES				*SAMPLE SIZE	NO. OF DEFECTIVES				ACCEPTED	REJECTED
				CRITICAL	MAJOR	MINOR A	MINOR B		CRITICAL	MAJOR	MINOR A	MINOR B		
8	1324	L	150	0	5	6	2							1324
9	1507	L	150	0	3	3	4						1507	
10	3107	L	150	0	1	0	8						3107	
11	2804	L	150	0	0	1	0						2804	
12	1473	L	150	0	0	0	0						1473	
13	1866	L	150	0	1	0	0						1866	
TOTAL	12081	XXXXX	900	0	10	10	14	XXXXX	XXXXX	XXX	XXX	XXX	10757	1324
PERCENT	XXXXX	XXXXX	XXXXX	0.00	1.11	1.11	1.56	XXXXX	XXXXX	XXX	XXX	XXX	89.04	10.96

NOTES: 1. Do not record resubmitted lot data on this form.
2. Use separate page for each item and for each independent station if there is more than one station for item.

*Where sample size varies within an inspection lot for the different classes of defectives, notation of such sample size(s) should be made under the class(es) concerned.

COMMENTS:

INSPECTOR (Signature)

a-19208

EXHIBIT IV

SUMMARY OF INSPECTION REPORTS FORM 1896 RECEIVED
FROM GROUPS I & II* FOR PERIOD JANUARY 15, 1951 THRU MARCH 8, 1951

Inspection District Manufacturer (Omitted) Item	Crit. P.A. 1	Major P.A. 2	Minor A P.A. 3	Minor B P.A. 4	No. of Lots Submitted 5	No. of Lots Accepted 6	% of Lots Observed 7	% of Lots Expected 8
INM BALTIMORE								
Gun Brackets for M38M24 (Army Dwg. 722681)	0.0	8.46	0.0	3.07	2	1	50.0	20.0[*2]
NOP MACON								
Elec. Primer Mk 42 Primer Stock & Insulator (685423)	0.00	0.50	0.14	0.00	26	24	92.3	99.0
Inner Ignition Cup & Electrode Sub-assembly (685425)	0.00	0.58	0.00	0.00	35	31	88.5	98.0[*4]
Adapter Plug (685430)	0.04	0.00	0.04	0.00	6	5	83.3	83.6[*5]
Tube (685431)	0.26	0.00	1.83	0.00	12	7	58.0	31.0[*6]
Electrode(685432)	0.00	0.09	0.41	0.00	15	15	100.0	99.0
Electrode Insulator (685436)	0.00	0.12	0.00	0.00	38	38	100.0	100.0-
VT Fuzes Sleeve w/diaphram (459563)	None	1.59	4.70		43	37	86.1	64.0[*7]
Threaded Insert (688454)	None	4.57	3.70		20	11	55.0	36.0[*7]

* 2. First lots. Note process average.
4. 74% of defects in 4 lots.
5. On tightened inspection
6. On tightened inspection. Rejected lots were consecutive. Subsequent lots indicate situation improved.
7. On tightened. Not conforming to sampling instructions. Letter being drafted.

and reports on the contract were made. For the first 10 lots, the process average was found to be 1.6 for major defectives and two or 20% of the lots were rejected. This percentage of lot rejection is found to be consistent with the operating characteristic curves shown on page 41 of MIL STD 105A, (Exhibit V) thus raising no doubt that material was homogeneous and the inspector's action normal with respect to this process average. Table II, limits of the process average, indicates that for this total sample size of 1500 (for the first ten lots) tightened inspection is not mandatory unless process average exceeds an upper limit of 1.75%. Therefore, normal inspection was still continued since this process average was not yet near the lower limit of the process average necessary before reduced inspection could be used. This is shown in Table II to be .25% defective. No critical defectives were found and the percentage of minor defects was well below required levels. Reports to the Bureau indicated that the material was consistent in quality with production under other contracts on the West coast. (Exhibit VI). Hence, the AQL was maintained at 1% as under normal procedures.

This example illustrates the use of MIL STD 105A upon a simple item. This item is inspected on the same basis as if produced in any other plant by any other producer or by the Navy itself. The item has been judged by the Standards established by the designer of the item and by his interpretation of the relative importance of each of the dimensions and tolerances specified. Judgment of the acceptance of the lots of items has been exactly the same as by any other inspector, no matter on whose payroll. The quality level for the material is found to be in keeping with the service requirements of the fleet as well as within production capabilities. This example shows how MIL STD 105A provides a generally recognized standard of quality for the item based upon the combination of technical and management skills. Judgment of quality also forms a base line from which to detect any later change in the material through deterioration, stowage, or accident in the future.

Section III Necessary Refinements in Application

If final products consisted of only one part and one operation, and if this could be offered to the government as a lot after all production of it had ceased, MIL STD 105A would leave few additional questions to be solved by those responsible for its administration. But the world of reality is far more complicated than this simple situation. Most products are composed of more than one part, some products being made up of thousands of individual piece-parts. These piece-parts may be offered for acceptance by themselves, or as part of purchased sub-assemblies, or only as part of the final product itself. The piece-parts may be produced by many contractors in many different plants. Therefore it is neither practical nor economical to have acceptance inspection only at the final product level, especially when some of the important requirements have been hidden or affected by subsequent production processes. Moreover, not all products can be brought together as a lot in the usual sense, in which case inspection stations in the process as well as provisions for inspection along moving assembly lines are necessary. And each of these complexities become further involved when small volume rather than large volume production is involved.

Not all these complexities can be discussed extensively within the scope of this paper. Immediately, however, two problems of major consideration in achieving a standard inspection system are raised. The first deals with the place of inspection within the framework of the present system of CD and AQL designation. This has ramifications with respect to consistency and uniformity of the established AQL's. The second major problem is concerned with the general simplification of the inspection system with a possible transition from the CD based upon component requirements to a system based more solidly on end product evaluation.

Under the present procedures, classification of defects are made for each product, subassembly, or piece-part thereof capable of or susceptible to separate manufacture. This, in fact, means that each part separately described by drawing or similar requirement is the basis for a classification. Therefore, Ordnance classifications of defects are identified by the drawing number of the part described. Where the item is composed of many parts each

requiring a separate drawing, as for example, in a mechanical time fuze, there are many classifications of defects that apply to the item. Where the item is composed of a single part, as in a cartridge case, only one classification of defects is appropriate for the item.

Classifications of defects are made by the design agency for new products. Since the designer has described the piece-part and established the required tolerances in view of the over-all performance required of the product, he is best prepared to judge the relative importance of each requirement and the possible effect of departures therefrom. The same considerations relating dimensions and tolerances to final performance are involved in the original design as in the classification of defects based thereon.

Some reformulation of the designer's thinking is necessary for CD preparation, for he must consider not only what the proper tolerance should be, but how important a departure from the tolerance is, scaling this importance into the categories of critical, major and minor defects according to the MIL STD 105A definitions given. And, since any departure if sufficiently large would be of major or critical importance, he must consider the effect of an out-of-tolerance dimension at a given point. The point depends to some extent on the AQL value, but is sufficiently close to one fourth of the tolerance spread beyond the tolerance limits to use this as a working rule of thumb.*2

CD's prepared in this manner are thus an extension or rather an interpretation of the drawings. Thus, they serve production as well as inspection in insuring that attention has been focused on meeting the important requirements in each piece-part at the expense, if unavoidable, of slighting the unimportant requirements. Process controls can be established, for instance, for each dimension involving a critical or major dimension. The CD's also provide uniform judgement wherever the piece-part is made, whether in separate establishments or in an integrated plant process.

Normal practice is to assign an AQL to each class of defects listed on each CD. Generally, as shown by normal practice, an AQL for major defects of 1% and for minor defects of 2½% is designated. Requirements for criticals also apply to each CD. Thus, if an item is composed of 300 piece parts, each of these has an applicable AQL. But the relationship between this multi-branched AQL and functioning requirements of the final item becomes difficult to establish in any practical way. This makes it difficult under the present system to develop the relationship between desired fleet performance and the levels of inspection for each item production.

Location of Inspection

Under these present procedures in which each piece-part or sub-assembly is accorded a separate CD and an AQL standard applies to each, the general questions raised by the inspector for the location of inspection stations (step II in the action of the inspector as previously described) can be set forth as follows:

(1) At what locations must stations be established to permit inspection for defects which would be hidden in the final assembly?

(2) At what location must the final station be established in order to insure that no operations (including material handling) which are likely to produce defects will be performed subsequent to the final station?

(3) At what locations must stations be established to allow action on defective lots prior to subsequent operations which would be hazardous or result in great cost in terms of salvage and scrap loss should they be performed on defective items?

*2 "Naval Ordnance Procedure in Classification of Defects" by C.C. Van Vechten and I.B. Altman, Industrial Quality Control, Vol. 5, No. 1, July 1948

EXHIBIT V

Table III.—*Sample size code letters**

Lot size	Inspection levels		
	I	II	III
2 to 8	A	A	C
501 to 800	H	J	L
801 to 1,300	I	K	L
1,301 to 3,200	J	L	M
3,201 to 8,000	L	M	N
8,001 to 22,000	M	N	O
22,001 to 110,000	N	O	P
110,001 to 550,000	O	P	Q
550,001 and over	P	Q	Q

*Sample size code letters given in body of table are applicable when the indicated inspection levels are to be used.

Table IV-A.—*Master table for normal and tightened inspection (Single sampling)*

Sample size code letter	Sample size	Acceptable Quality Levels (normal inspection)												
		0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↑
B	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1
C	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↕
D	7	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↕	↕
E	10	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↕	↕	1 2
F	15	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↕	↕	1 2	2 3
G	25	↓	↓	↓	↓	↓	↓	↓	0 1	↕	↕	1 2	2 3	3 4
H	35	↓	↓	↓	↓	↓	↓	0 1	↕	↕	1 2	2 3	3 4	5 6
I	50	↓	↓	↓	↓	↓	0 1	↕	↕	1 2	2 3	3 4	4 5	6 7
J	75	↓	↓	↓	↓	0 1	↕	↕	1 2	2 3	3 4	4 5	6 7	9 10
K	110	↓	↓	↓	0 1	↕	↕	1 2	2 3	3 4	4 5	6 7	8 9	12 13
L	150	↓	↓	0 1	↕	↕	1 2	2 3	3 4	4 5	5 6	8 9	11 12	17 18
M	225	↓	0 1	↕	↕	1 2	2 3	3 4	4 5	5 6	8 9	11 12	17 18	24 25
N	300	0 1	↕	↕	1 2	2 3	3 4	4 5	5 6	7 8	10 11	14 15	20 21	32 33
O	450	↕	↕	1 2	2 3	3 4	4 5	5 6	7 8	10 11	14 15	20 21	29 30	43 44
P	750	↕	1 2	2 3	3 4	4 5	6 7	8 9	11 12	15 16	20 21	31 32	45 46	68 69
Q	1500	1 2	2 3	3 4	5 6	7 8	9 10	13 14	18 19	25 26	35 36	56 57	81 82	124 125
		0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
		Acceptable Quality Levels (tightened inspection)												

↓—Use first sampling plan below arrow. When sample size equals or exceeds lot size, do 100 percent inspection.

↑—Use first sampling plan above arrow.

Ac—Acceptance number.
Re—Rejection number.

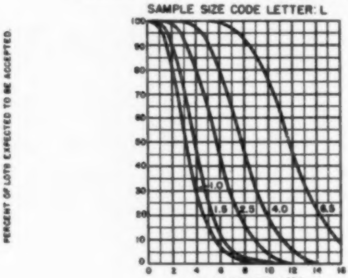
Tightened sampling plans are not provided for AQL 0.015.

Table VI-L—Sampling plans for sample size code letter: L—Continued

OPERATING CHARACTERISTIC
CURVES FOR SINGLE SAMPLING PLANS

(Curves for double and multiple sampling are essentially equivalent)

SAMPLE SIZE CODE LETTER: L



QUALITY OF SUBMITTED LOTS
(in percent defective or defects per hundred units)

Note: Figures on curves are Acceptable Quality Levels for normal inspection.

Table II.—*Limits of the process average*—Continued

(Upper limits for AQL's from 0.015 to 4.0)

Number of sample units included in estimated process average	Acceptable quality levels											
	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0
25–34	(**)	(**)	(**)	(**)	(**)	(**)	(**)	5.103	6.52	8.27	11.23	15.05
35–49	(**)	(**)	(**)	(**)	(**)	(**)	3.328	4.383	5.63	7.17	9.82	13.26
50–74	(**)	(**)	(**)	(**)	(**)	2.155	2.810	3.722	4.81	6.17	8.52	11.62
1,300–1,499	0.113	0.185	0.270	0.354	0.461	0.651	0.907	1.296	1.80	2.48	3.77	5.60
1,500–1,699	0.107	0.175	0.256	0.337	0.440	0.625	0.874	1.255	1.75	2.42	3.69	5.50
1,700–1,899	0.102	0.167	0.245	0.324	0.424	0.604	0.847	1.220	1.71	2.37	3.59	5.41
17,500–22,499	0.041	0.075	0.119	0.167	0.232	0.356	0.534	0.821	1.21	1.76	2.84	4.42
22,500 and up	0.036	0.067	0.109	0.155	0.217	0.337	0.510	0.790	1.17	1.71	2.77	4.35

**Normal inspection for these AQL's does not provide sample sizes this small.

Table II.—*Limits of the process average*

(Lower limits for AQL's from 0.015 to 4.0)

Number of sample units included in estimated process average	Acceptable quality levels											
	0.015	0.035	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0
25–34	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)
35–49	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)
50–74	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)	(*)
1,300–1,499	(*)	(*)	(*)	(*)	(*)	(*)	(*)	0.004	0.20	0.52	1.23	2.40
1,500–1,699	(*)	(*)	(*)	(*)	(*)	(*)	(*)	0.045	0.25	0.58	1.31	2.50
1,700–1,899	(*)	(*)	(*)	(*)	(*)	(*)	(*)	0.080	0.29	0.63	1.41	2.59
1,900–2,249	(*)	(*)	(*)	(*)	(*)	(*)	(*)	0.119	0.34	0.69	1.46	2.68
2,250–2,749	(*)	(*)	(*)	(*)	(*)	(*)	0.021	0.166	0.40	0.77	1.55	2.80
2,750–3,499	(*)	(*)	(*)	(*)	(*)	(*)	0.061	0.217	0.46	0.84	1.65	2.93
17,500–22,499	(*)	(*)	0.011	0.033	0.068	0.144	0.266	0.479	0.79	1.24	2.16	3.58
22,500 and up	(*)	0.003	0.021	0.045	0.083	0.163	0.290	0.510	0.83	1.29	2.23	3.65

* Number of sample units included in estimated process average is insufficient for reduced inspection.

(4) Of the possible alternatives listed which ones are preferred in terms of available work space, space for forming items into standing lots within limitations of safety requirements, access to any required utilities (heat, light, power, special equipment), personnel?

(5) Can any of the stations listed be combined to advantage?

(6) Can duplication of effort be eliminated by shifting specific independent inspections from one station to another?

These problems of determining the proper location of inspection stations reveal some of the difficulties of attaining uniformity and standardization in levels of quality as among different activities. If each piece is procured separately, a place of inspection is usually determined as in the simple case and the problem of inspection only involves that of the assembly into the comprehensive unit. Also, if each piece-part can be separately considered by the inspector at a given place in the process then the simple case largely applies. However, in any assembly process, there is the tendency on the one hand to combine inspection under many CD's at a given inspection station and an opposite tendency to break down a given CD to many inspection points over a moving line during a sub-assembly build-up.

Obviously, when several CD's are brought together at one inspection station, the combined AQL and the probability of lot acceptance for given quality should correspond to the situation where each of the piece-parts is inspected separately. This correspondence is sometimes secured by mathematically combining the AQL's on a root-mean-square basis in order to arrive at comparable standards; but there has been no established policy to uniformly treat this situation, and it is difficult to administer in practice.

The stretching out of a single classification of defects over several inspection points in a buildup of a product is sometimes considered desirable because of the inability to inspect or test the built-up product without destruction. In this case, lot rejection for defects, repairable if found earlier in the process, usually involves destruction of the rejected lot and the consequent waste of manpower and materials. Pychologically, the inspectors prefer to reject material at points where it can be screened or repaired. The breakdown of an end sub-assembly inspection to more immediate inspection at points of buildu is in keeping with the over-all philosophy that inspection points should be those where the overall loss in labor and materials from lot rejection is at a minimum point. Nevertheless, when a single CD with its assigned AQL is broken down into a series of inspections, the problem of breaking down the AQL into its proper components at each inspection point is the inverse of the problem of AQL combination indicated above. Study of this problem on an administrative level is being carried on to attain a standardized procedure that will provide uniform quality protection regardless of individual plant situations which motivate CD combination or CD breakdown along an assembly process.

When products are not simple, the assignment of set AQL values are also difficult. It has been seen that a shift in the method of preparation of CD's or a change in the location in the point of inspection has a profound effect on the residual acceptance quality level assigned.

The present practice is to assign AQL values for Major and Minor defects on a standard basis. These values are given in the normal inspection procedure. Frequently, the normal AQL is modified to account for special service requirements for the item, or to allow for acknowledged and uniform inability of contractors to meet the normal AQL on a particular item. However, few changes in AQL have been made in the past.

It is expected that with the accumulation of production experience on comparative process averages for similar items and with the more efficient accumulation of inspection data, a closer analysis of the relationship between service needs and the inspection levels of quality will make for frequent changes and flexibility in the assignment of AQL in the future.

These considerations lead to the second general problem, that is, whether a simplification of the present inspection system can be made with a transition from the piece-part CD system to one based on end product requirements. Subh a product requirement inspection system would start with the final product requirements and evaluated performance characteristics only as far back into the sub-assembly and piece-part stage as necessary to gain the necessary assurance of quality. Thus with a mechanical time fuze made of some 300 parts, a single performance timing test might give as satisfactory a measure of assurance of the quality of the product as the much larger amount of government inspection as the present system provides. With other products, it might be necessary to inspect at a sub-assembly level or even lower, in order to observe characteristics not readily measured in the final product. In each case how far the inspection must be extended depends upon a variety of considerations.

Commercial type products or those for which performance requirements explicitly stated and examined by test are most easily handled. Specially designed products, most common in BUORD procurement, would require careful description of the final or intermediate tests and correlation with the piece-part requirements as designed. Care would need to be exercised that the tests adequately described requirements over all conditions intended by the designer and this might not be a simple task. Moreover, the requirements would include not only those dealing with performance but those entailing life, durability and safety as well. Assurance as to each of the requirements would have to be carried down to the level of interchangeability in fleet use or in possible repair, maintenance or overhaul. It would also extend to piece-parts made in separate plants or procured under separate contract and furnished to assemblers as government material (GFM). And where contractors obtained material and parts on sub-contract, it would imply their use of a CD system as based on present standards. Finally, assurance as to quality of piece-parts and sub-assemblies would have to be obtained where necessary to prevent unnecessary scrap and waste from delayed rejection in the absence of satisfactory production controls especially in time of labor and material scarcity and in pseudo cost-plus situations.

It is apparent that when these considerations are followed through, inspection of simple products based on this end requirements approach would come to almost the same as under the present administrative system. However, the degree of separation would presumably be in proportion to the product complexity, the extent of satisfactory production controls preventing waste from delayed rejection, and the availability of final test for all performance requirements.

In special cases of complex products in small volume production, such a system of inspection is already being used. In this system, inspection is placed as near to the final product as possible consistent with the adequate check of product requirements including interchangeability, life and function. Units of inspection are established for which external effects (factors relating to end product performance) are measured, and below which internal effects (relating to dimensions within unit which may involve offsetting errors) are of little consequence. Acceptance inspection for these items is thus reduced to a minimum consistent with an adequate check of the interchangeability, life and function requirements. This system developed from the impossibility of performing acceptance inspection on each piece-part of very complex items in low volume production. Since there is no satisfactory dividing line between complex products and simple ones, it is likely that similar procedures in the inspection of semi-complex items of moderate scale production will be followed. Although these systems save on the actual acceptance inspection and require different focus of defect classification, they do not diminish the usefulness of the piece-part classifications in guiding production. Therefore, it is likely that the present system of defect classification, although continued as a guide to production, will be modified by an end use means of determining the items of inspection.

This paper has dealt with the administrative framework in which MIL STD 105A is applied. It has shown that it is very workable when applied to simple products. It has also shown that there are many difficulties in achieving a satisfactory standard for control when dealing with non-simple or complex products. The Classification of Defects based on present procedures provide an excellent guide to the producer as well as to the inspector with respect to the intention of the designer. They are relatively easy to prepare and to administer. But for products composed of many parts, they are bulky and extensive, involve problems concerning the standardization of quality levels and are difficult to summarize and compare with service needs. Many of these difficulties may be obviated by a transition to an end product requirement inspection while at the same time the present defect classifications are retained as production guides.